AIRPLANE MAINTENANCE SCHEDULING WITH MAINTENANCE CREW ASSIGNMENT

BY

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Dedicated to my family and my friends

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In the name of ALLAH, the most compassionate and the most merciful

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LIST OF ABBREVIATIONS

FAA	:	Federal Aviation Administration
PM	:	Preventive Maintenance
MILP	:	Mixed Integer-Linear Program
AMS	:	Airplane Maintenance Scheduling
AMCA	:	Airplane Maintenance Crew Assignment

ABSTRACT

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Airline industry is one of the important industries in the world. There are many decision making problems that play critical role in airline industry and one of them is maintenance operation problem. The research should answer the two following question. When to call the airplanes for the maintenance checks? How to distribute the maintenance crew on the ground to perform the maintenance check for the airplanes? The two problems where studied separately and two mixed-linear integer program models (MILP) is formulated to solve the airplane maintenance scheduling (AMS) problem and airplane maintenance crew assignment (AMCA) problem. The objective of MILP in AMCA problem is to minimize total ground cost of maintaining airplanes while performing necessary jobs. The objective in AMS problem is to maximize flying hours given that the airplane can only perform maintenance in given time window of flown hours and the maintenance center can only perform maintenance for certain number of airplanes. Illustrative examples are solved for each problem and both models shows fast solution in computational time. Also, a heuristic approach is used to combine both problems and illustrative examples were solved.

Keywords: optimization, mixed-integer linear program, airplane maintenance scheduling, crew assignment, heuristic.

ملخص الرسالة

الاسم الكامل: محمد حسن يوسف اليعقوب

عنوان الرسالة: جدولة صيانة الطائرات مع توزيع عمال الصيانه

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شركات الطيران هي من أحد أهم الصناعات في العالم. هنالك العديد من القرارات التي تلعب دوا حاسما في شركات الطيران و من أحد هذه القرارات مسئلة عمليات الصيانه.ينبغي على هذا البحث الاجابه على السؤالين التاليين. متى نستدعي الطائرات الى الصيانه الدوريه؟ كيفية توزيع عمال الصيانه على أرض العمل لاتمام الصيانه المطلوبه للطائرات؟ لقد تم التعامل مع المسئلتين على حدا و تم انشاء برنامجين بأستخدام البرمجه الخطيه المختلطه لحل جدولة صيانة الطائرات و توزيع أو تعيين عمال الصيانه لصيانة الطائرات. الهدف في البرنامج في مسئلة توزيع العمال هو أيجاد التوزيع المثالي للعمال الذي يقلل من تكلفة وجود الطائرات على الأرض مع أداء كافة الصيانه المطلوبه للطائرات.و في مسئلة جدولة صيانة الطائرات كان هدف البرنامج هو ايجاد عدد ساعات الطيران القصوى التي يمكن للطائره تنفيدها مع مراعات أن هناك صيانات دوريه للطائره تتم في فتره محدده من ساعات الطيران المنفذه و مركز صيانة الطائرات لديه أمكانيه لعمل الصيانه لعدد محدد من الطائرات. أمثله توضيحيه حلت لكلى المسئلتين و البرنامجيين يظهران سرعه في أيجاد الحل المثالي. أيضا تم أنشاء برمجه أرشاديه لدمج المسئلتين و أمثله توضيحيه حلت لتوضيح طريقة العمل. وأعدت الرسالة توصيات بالأبحاث المستقبلية في مجال الاطروحة.

CHAPTER 1

INTRODUCTION

1.1 Overview

The airline industry is a major transportation industry that plays critical role in the world. This applies to either passenger or cargo transportation. There are many decision making problems that have main role in airline industry and one of them is airplane maintenance operation. Even though the maintenance operation problem comes at the end stage of airline operations, it has a lot of potentials for cost saving. The implementation of maintenance is very critical because any break down of an aircraft during flight could results in life loss and any overrated maintenance may cause delay in flight schedule which result in loss of revenue.

Maintenance of the airplane occurs at defined intervals. The standard intervals are named and specified by the manufacturer. However, individual airlines can come up with their named interval as long they keep the integrity of the original maintenance task or receive approval from the Federal Aviation Administration (FAA) for deviation. The standard intervals are as follow [11]:

- Transit Checks

  A transit check is performed after landing and before the next take off. It consists of oil level check, fill actions and a general visual inspection, called a walk-around, to check for any fluid leaks, open or loose panels and damage to the flight control surfaces or antennae.

- 48-hour checks

  A 48-hour check is performed once every 48 hours and it replaces the daily check. This check includes tasks that are more detailed than the transit check.

- Hourly limit checks

  Certain checks determined by the number of hours the unit or system has been operating. This approach is used for engines, airplane flights controls and numerous other systems that are operating on a continuous basis during the flight or on the ground.

- Operating cycle limit checks

  Checks determined by the number of operating cycles that have endured. This approach is used for systems such as tires, brakes and landing gears.

- Letter checks

  Letter checks are a combination of hourly and cycle limit checks that are grouped together to make four letter checks A, B, C and D [21]. The implementation of big check tasks includes the small check tasks for example if maintenance check B has been done to the airplane then there

is no need to perform maintenance check A (See Figure 1-1).Table 1-1 summaries typical maintenance checks intervals.

The aircraft maintenance checks are done by qualified engineers who have received training in order to get their licenses. There are five basic categories of aircraft maintenance engineer's licenses [5]. These are Airframes, Engines, Instruments, Electrical and Radio.

Each maintenance check has a tasks package which contains a collection of work orders that must be completed in different sectors in the airplane. Every airplane type and maintenance check has its own tasks package. See Table 1-2

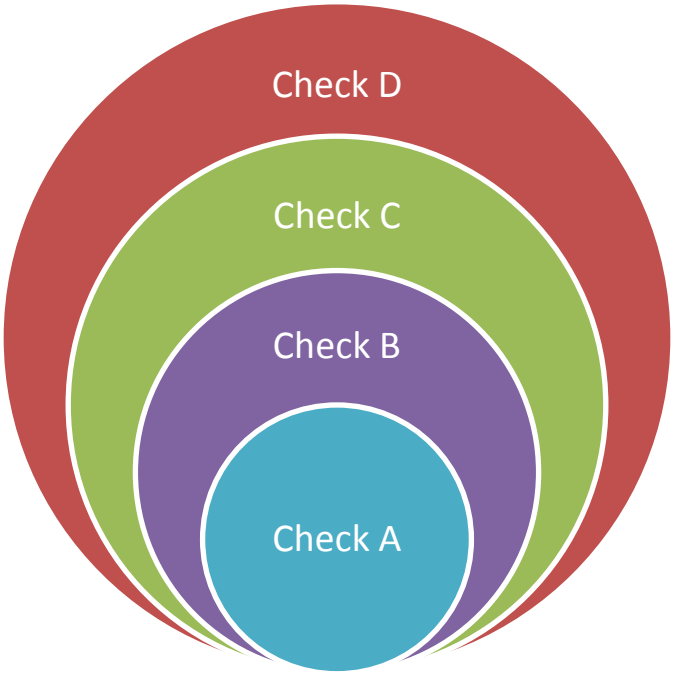

Figure 1-1: Performing big maintenance check contains the tasks of small maintenance checks.

Table 1-1: Typical maintenance checks intervals*.

Aircraft	'A' Check	'B' Check	'C' Check	'D' Check
B737-300	275 FH	825 FH	18 months	48 months
B737-400	275 FH	825 FH	18 months	48 months
B737-500	275 FH	825 FH	18 months	48 months
B737-800	500 FH	n/a	4000-6000 FH	96-144 months
B757-200	500-600 FH	n/a	18 months / 6000 FH / 3000 FC	72 months
B767-300ER	600 FH	n/a	18 months / 6000 FH	72 months
B747-400	600 FH	n/a	18 months / 7500 FH	72 months
B777-300	1000 FH	n/a	32 months/ 12000 FH/3000 FC	128 months / 48000 FH/ 12000 FC
B777-200	600 FH	n/a	30 months/ 7500 FH/5000 FC	120 months / 30000 FH/ 20000 FC
A319	600 FH	n/a	18-20 months / 6000 FH / 3000 FC	72 months
A320	600 FH	n/a	18-20 months / 6000 FH / 3000 FC	72 months
A321	600 FH	n/a	18-20 months / 6000 FH / 3000 FC	72 months
A330-343	800 FH	n/a	18 months/ 5400 FH /2460 FC	144 months /43200 FH /19680 FC
ATR42-300	300-500 FH	n/a	3000-4000 FH	96 months
ATR72-200	300-500 FH	n/a	3000-4000 FH	96 months
MD11	600 FH	n/a	21 months / 7000 FH	42000 FH/126 months
ERJ-170	600 FH	n/a	24 months/ 6000 FH	96 months /24000 FH /20000 FC

* FH is flying hours, FC is flying cycles and n/a is not applicable

Table 1-2: Description of typical maintenance checks.

Check	Location	Description	Duration
'Line' /'transit'	At gate	Daily (before first flight or after landing and before the next take off). Visual inspection; fluid levels; tires and brakes; emergency equipment	≈1 hour
'A'	At gate	Routine light maintenance; engine inspection	≈10 hours(1 working shift)
'B'	At gate	Similar to A check but with different tasks	≈10 hours - 1 day
'C'	Hangar	Structural inspection of airframe, opening access panels; routine and non-routine maintenance; run-in tests	≈3 days - 1 week
'D'	Hangar	Major structural inspection of airframe after paint removal; engines, landing gear and flaps removed; instruments, electronic and electrical equipment removed; interior fittings(seats and panels) removed; hydraulic and pneumatic components removed	≈1 month

1.2 Objective of This Thesis

Our objective in this research is to answer the following two questions:

1- When to call the airplanes to perform maintenance checks?
2- How to distribute the maintenance crew on the ground to perform the maintenance for the airplane?

Each of the above questions will be addressed by developing an MILP. An answer to both questions is formulated as a simple heuristic method.

1.3 Thesis Organization

The thesis is organized into six chapters; Chapter two presents literature review, Chapter three introduce the Mixed-Integer Linear Program (MILP) Model for airplane Maintenance Crew Assignment (AMCA), Chapter four is about Airplane Maintenance Scheduling (AMS), Chapter five presents heuristic steps to solve airplane maintenance scheduling with maintenance crew assignment problem and Chapter six is the conclusion for this thesis.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter contains a literature review of some research work related to the thesis objectives. It is divided into three sections. The first section will review papers related to maintenance crew assignment. The second section will give an overview about topics that is related to airplane maintenance scheduling. The final section will conclude this chapter.

2.2 Airplane Maintenance Crew Assignment

In 1999, Hesham Al-Fares [3] performed a study to determine the optimum maintenance workforce schedule to satisfy growing labor requirements with minimum cost. A new integer programming formulation was developed to obtain an optimum seven-day work schedule with no increase in workforce size. The main recommendation of that study was to switch from a five-day to a seven-day workweek for aircraft maintenance workers.

A mixed integer programming model was formulated by Yang et al. [23]. The model has various flexible strategies so that an airline can effectively manage its maintenance manpower supply. In order to evaluate the model performance, the authors used an operating data from a leading Taiwanese airline and solved the mathematical model using commercial software package CPLEX.

Ahire et al. [2], used evolution strategy to minimize the make-span for a set of preventive maintenance tasks, requiring single or multiple skills, within workforce availability constraints for heavy equipment overhaul facilities such as aircraft service centers and railroad yards. A large scale problem was solved using evolution strategies and it converges faster to optimality than simulated annealing.

Simulation model [4] was used to solve manpower maintenance planning for line or transit maintenance problem with three pools that represents the shifts “Day, swing and night” .Sensitivity analysis was used to evaluate different scenarios. The simulation technique shows that changing of the shift schedule can greatly enhance the efficiency of the existing system.

In 2004, a study was conducted by Yan et al. [22] to help airline to efficiently and effectively plan their maintenance manpower supplies to deal with multiple aircraft type maintenance certification. The authors developed mixed integer programming model which is characterized as NP-hard. Because of the problem size of the proposed model was expected to be huge, they developed a heuristic algorithm to solve the problem. They performed a case study to evaluate the model and the solution algorithm using the operation data from Taiwan airline.

A manpower scheduling for aircraft maintenance was studied by Sze et al. [19]. The focus of the study was on in-flight food loading operation where a group of loading teams with flexible shifts is required to deliver and upload packaged meals from the ground kitchen to aircrafts in multiple trips. All aircrafts must be served within predefined time windows. The study took in consideration various constraints such as

meal break allocation, multi-trip traveling and food exposure time limit. Considering the aircrafts movement and predefined maximum working hours for each loading team, the main objective of this study is to form an efficient roster by assigning a minimum number of loading teams to the aircrafts. An insertion based heuristic was proposed to generate the solutions in a short period of time for large instances. The algorithm was implemented in various stages to construct trips and the results show that the insertion heuristic more efficiently outperforms the company's current practice.

The problem of workforce-constrained maintenance scheduling for military aircraft was studied by Safaei et al. [15]. The military aircraft fleet has flying program and availability of the aircraft is a challenging issue. During the pre- or after-flight inspections, some component failures of the aircraft may be found. This requires the aircraft to be sent to the repair shot to be scheduled for maintenance jobs, consisting of failure repairs or preventive maintenance tasks. The research objective is to schedule the jobs in such a way that sufficient number of aircrafts is available for the next flight programs and the main resource, as well the main constraint, in the shop is the skilled-workforce. The authors formulated the problem as a mixed-integer programming model. The proposed model is solved using classical Branch-and-Bound method and its performance is verified and analyzed in terms of a number of test problems adopted from the real data. The results empirically supported practical utility of the proposed model.

San-Nah Sze [18] performed a study for a real-life manpower scheduling problem with maintenance operations in multiple trips traveling at airport. Maintenance teams are required to travel from a common service center and serve the aircrafts within their transit times. Also, the model takes into account scheduling a meal break, truck capacity,

synchronization of teams and trip travelling time limit. The objective was to develop an efficient heuristic solution to generate minimum maintenance teams for maintenance operations. A Two-Stage Scheduling Heuristic and an Insertion Algorithm were proposed for different variants of the problem. Computational results show the efficiency and effectiveness of proposed algorithms. Both heuristic solutions are efficient in handling large problem instances and easily adapted to complex scheduling environments.

2.3 Airplane Maintenance Scheduling

Feo and Bard [8] presented a model that can be used by planners to both locate maintenance stations and to develop flight schedules that better meet the cyclical demand for maintenance. They formulated the problem as a min-cost, multi-commodity flow network with integral constraints. They solved the problem as a two-phase heuristic and the procedure is demonstrated with data supplied by American Airlines for their Boeing 727 fleet.

Gopalan and Talluri [9] introduced fast and simple polynomial-time algorithms for finding a routing of aircraft in a graph whose routings during the day are fixed, that satisfies both the three-day maintenance as well as the balance-check visit requirements under two different models: a static infinite-horizon model and a dynamic finite-horizon model. Also, they discussed an implementation of a three-stage procedure for finding a maintenance routing of aircraft where they used the static infinite-horizon model.

Sarac et al. [16] focused on aircraft routing problem which involves generating and selecting a particular route for each aircraft of a sub-fleet that is already assigned to a set of feasible sequences of flight legs. The authors developed an operational aircraft

maintenance routing problem formulation that includes maintenance resource availability constraints and they proposed a branch-and-price algorithm for solving that problem.

In [1], the research objective was to search the efficiency of the proposed method on rolling horizon and to compare different types of maintenance policies given a flight schedule for a specific aircraft fleet. Afsar et al. proposed a method to maximize the aircraft utilization before the maintenance interventions and smooth's the flight load of the aircrafts so that the maintenance checks are regular for all the fleet.

In [13], given a set of scheduled flights that must be operated by the same aircraft type, the aircraft routing problem consists of building anonymous aircraft routes that respect maintenance requirements and cover each flight exactly once. Lacasse-Guay et al. introduced a classification according to three business processes that are used to assign the anonymous routes to the specific aircraft tail numbers. Also, the authors compared the aircraft routing problem variants resulting from these three processes with regard to their adaptability to different contexts, the difficulty of solving them, the cost of the computed solutions, and the robustness of these solutions.

In 2010, Keysan et al. [10] had addressed both tactical and operational planning for scheduled maintenance of per-seat, on-demand air transportation. At the tactical level, the authors determined the daily maintenance capacities. As the fleet size grows over time, decisions pertaining to when and how much to increase maintenance capacity is made. At the operational level, they assigned itineraries to jets and determine the jets to be maintained on a daily basis.

The work in [17] studied the aircraft maintenance-scheduling problem given a flight schedule with aircraft assigned to it. The objective is to determine which aircraft should fly which segment and when and where each aircraft should undergo different levels of maintenance check required by the FAA while minimizing the maintenance cost and any costs incurred during the re-assignment of aircraft to the flight segments. The maintenance-scheduling problem is formulated by Siriam and Haghani as a min-cost multi-commodity network flow model with integer restrictions on the variables and heuristic approach is used to solve the problem. The heuristic procedure provides good solutions in reasonable computation time and the model can be used by mid-sized airline corporations to optimize their maintenance costs.

In 2000, for the problem of assigning planes to flights and of fleet maintenance operations scheduling, El-Moudani and Mora-Camino [7] proposed a dynamic to face on-line operation conditions. The authours proposed solution mixes a Dynamic Programming approach (to solve the fleet assignment problem) and a heuristic technique (to solve the embedded maintenance schedule problem). Their approach shows acceptability characteristics for operational staffs, while providing efficient solutions when applied to a medium charter airline. The proposed solution scheme can be considered as the basis for the development of an on-line decision support system for fleet operations management within airlines.

For the problem in the integrated aircraft routing, crew scheduling and flight retiming problem, a minimum-cost set of aircraft routes and crew pairings must be constructed while choosing a departure time for each flight leg within a given time window. Mercier and Soumis [14] proposed a compact formulation of the problem and a

Benders decomposition method with a dynamic constraint generation procedure to solve it. Computational experiments performed on test instances provided by two major airlines show that allowing some flexibility on the departure times within an integrated model yields significant cost savings while ensuring the feasibility of the resulting aircraft routes and crew pairings.

In 2010, Eggenberg et al. [6] considered the recovery of an airline schedule after an unforeseen event called disruption which makes the planned schedule infeasible. The authors presented a modeling framework that allows the consideration of operational constraints within a Column Generation (CG) scheme. They introduced the general concept of recovery network, generated for each individual unit of the problem and showed how unit-specific constraints are modeled using resources. Also, they embed operational maintenance planning into a framework that captures the interaction between maintenance decisions and daily flight scheduling.

Kozanidis et al. [12] performed a study in flight and maintenance planning of military aircraft. The study addressed the problem of deciding which available aircraft to fly and for how long and which grounded aircraft to perform maintenance operations on, in a group of aircraft that comprise a combat unit. The objective is to achieve maximum availability of the unit over the planning horizon. An optimization model was developed and a real life example is solved to illustrate how it works using data from Hellenic Air Force. The authors proposed two heuristic techniques for solving large-scale instances of the problem.

2.4 Conclusion

This chapter reviewed the literature in the areas relevant to thesis. The review covered maintenance crew assignment and aircraft maintenance scheduling. The research for AMCA in the literature covered manpower scheduling for shifts and line maintenance problems. For AMS literature the research covered airplane maintenance routing problems, maintenance scheduling for short period and scheduling for rolling horizon for short period too. This thesis covers the AMS & AMCA in approach that never been done before.

CHAPTER 3

AIRPLANE MAINTENANCE CREW ASSIGNMEMT

3.1 Introduction

This chapter is about airplane maintenance crew assignment and it is divided into three sections. The first section contains the description and assumption for the problem. The second section presents an integer-linear model and the final section is numerical examples to demonstrate how the model works.

3.2 Problem Description and Assumptions

3.2.1 Problem Description

In order to perform a complete maintenance check for an airplane, different maintenance activities must be performed to the airplane. Examples for such activities are Avionics, Power Plant, Airframe and Cabin.

These jobs can only be performed by workers that are trained in that specific field, so in each of these activities we have certain number of workers that are capable of doing that work.

Each Maintenance check requires a known number of man-shifts or man-day for different activities. For example, a maintenance check that requires 20 man-shift can be performed by 20 men in one shift or in several shifts such that the total workers in these shifts is 20.

The airplane on the ground for maintenance costs the airline money for not utilizing it. Given these information, we can determine maintenance crew working schedule to minimize the total ground cost of the airplanes.

3.2.2 Model Assumptions

1- The time taken to finish the job is deterministic.

2- The number of workers for each job is deterministic.

3- Assigned workers cannot be shifted or moved to another airplane until the assigned period ends.

4- The job required for airplane can be performed in separated periods.

5- Workers are specialized in one type of job.

3.3 The Integer-Linear Programming Model

3.3.1 Parameters

i is the index for the airplane $i = 1,2, \dots \dots I$.

j is the index of kind of job $j = 1,2, \dots \dots . . J$.

k is the index for the period $k = 1,2, \dots . . K$.

C_{ij0} is the required time to perform job j in airplane i at the start of maintenance.

GC_i is the ground cost for airplane i per period.

WA_{jk} is the number of workers available to do job j during period k.

B is a large number.

3.3.2 The Decision Variables

W_{ijk} is the number of workers assigned for airplane i to do job j during period k.

C_{ijk} time remaining to complete job j at airplane i after period k.

D_{ij} is the time when job j on airplane i is completely done.

COM_i is the time when all jobs on airplane i is completely done (the completion time of maintenance on airplane).

x_{ijk} binary variables that take value 1 when job j for airplane i completed and 0 otherwise.

y_{ijk} record the time period when job j in airplane i is done.

3.3.3 Integer-Linear Model

The objective function is to minimize the sum of ground cost for all airplanes.

$$Min \sum_{i=1}^{I} GC_i \times COM_i \tag{3.1}$$

Subject to

The assigned workers must not exceed the available number of workers.

$$\sum_{i=1}^{I} W_{ijk} \leq WA_{jk}; \qquad for\ j = 1,2 \ldots . Jand\ k = 1,2, \ldots K. \tag{3.2}$$

Calculating the remaining time required to finish jobs.

$$C_{ijk} = C_{ij(k-1)} - W_{ijk}; \quad for\ i = 1,2, \ldots I\ , j = 1,2,3 \ldots , J\ and\ k = 1,2, \ldots , K \tag{3.3}$$

If the remaining time to accomplish the job is zero then set $x_{ijk} = 1$ otherwise $x_{ijk} = 0$.

$$C_{ijk} \geq 1 - x_{ijk} \geq \frac{C_{ijk}}{B}; \quad for\ i = 1,2, \ldots . I\ , j = 1,2, \ldots , J\ and\ k = 1,2, \ldots , K. \tag{3.4}$$

Record the period when job j on airplane i is completed.

$$y_{ijk} = \left(x_{ijk} - x_{ij(k-1)}\right) \times k; \qquad for\ i = 1,2, \ldots . I\ , j = 1,2, \ldots , J \quad and\ k = 1,2, \ldots , K. \tag{3.5}$$

Record the time when job j on airplane i is completed.

$$D_{ij} = \sum_{k=1}^{K} y_{ijk}\ ; \ \ for\ \ i = 1,2, \ldots I\ and\ j = 1,2\ , \ldots J. \tag{3.6}$$

Record the time when the maintenance of airplane i is completed.

$$COM_i \geq D_{ij}; \qquad for\ j = 1,2, \dots J\ and\ i = 1,2 \dots I \tag{3.7}$$

3.4 Numerical Examples

We solved six examples for different numbers of airplanes from 2 to 7. Example 6 is presented in this section and the rest are in Appendix A. Table 3-1 shows example 6 with 7 airplanes where avionics, power plant, airframe and cabin are jobs to be performed and the time required to perform the maintenance for each job is given in man-day. The ground cost per day for each airplane is given and the number of workers available for each job is known. Table 3-2 shows the solution for example 6 where the number of workers assigned for each job from day 1 to 20 is given in the table. The total cost for the optimal solution is 388612 SR.

LINGO 12.0 software package is used on PC with Windows 7 Professional, processor intel (R) core(TM) i5-2500 CPU @ 3.30GHz 3.30 GHz , installed memory (RAM) 8GB and 32-bit operating system to solve these examples. Table 3-3 shows the number of airplanes, variables, integer variables, constraints and elapsed runtime for each example solved. The AMCA problem can be solved very fast for problems with 2 to 7 airplanes but for more it will take longer time. An example of 8 airplanes was run for a week in LINGO 12 software package and optimal solution was not achieved.

Table 3-1: AMCA problem example 6 with seven airplanes.

Example6	Man-day needed to complete the job				Ground time cost SR/Day
Aircrafts	Avionics	Power Plant	Airframe	Cabin	
1	95	26	33	65	5929
2	78	19	60	49	11153
3	28	61	111	23	3406
4	24	40	101	42	9897
5	93	24	67	49	2687
6	42	20	51	63	2916
7	99	79	57	32	9088
Number of worker available	30	30	25	35	

Table 3-2: Solution for AMCA example 6 with seven airplanes.

		Number of workers assigned at each day																			
Airplane	Jobs	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	Avionics				3			6	30	26	30										
	Power Plant	26																			
	Airframe										8	25									
	Cabin				14				8	35	8										
2	Avionics	30	30	18																	
	Power Plant	4	5	10																	
	Airframe	17	25	18																	
	Cabin	3	11	35																	
3	Avionics															19	9				
	Power Plant					1			30	30											
	Airframe																11	25	25	25	25
	Cabin		23																		
4	Avionics							24													
	Power Plant					10		30													
	Airframe	2					25	25	25	24											
	Cabin				7	35															
5	Avionics											22		30	30	11					
	Power Plant		24																		
	Airframe										17				25	25					
	Cabin				14		35			4											
6	Avionics									4		8	30								
	Power Plant			20																	
	Airframe									1			25	25							
	Cabin		1					35	27												
7	Avionics			12	27	30	30														
	Power Plant		1		30	18	30														
	Airframe			7	25	25															
	Cabin	32																			

Table 3-3: Model Information for AMCA problems solved.

Example	Number of Airplanes	Number of Variables	Number of Integer Variables	Number of Constraints	Runtime (h,mm,ss)
1	2	202	96	289	0:00:00
2	3	495	240	677	0:00:02
3	4	852	416	1141	0:00:07
4	5	985	480	1309	0:01:49
5	6	1470	720	1933	19:19:14
6	7	2387	1176	3109	21:01:43

3.5 Heuristic Methods

In this section we introduce a heuristic method to solve AMCA problem. The motivation for this is to find a solution for large problem in reasonable time. In this heuristic, we use two costs ratio methods to assign the priority for the airplanes as described below:

1. Calculate Cost Ratio for all airplanes using one of the following methods:
   - Max Ratio cost $R_i = GC_i \times \max_{1 \le j \le J}\{\frac{C_{ij0}}{WA_{j1}}\}$
   - Total Ratio cost $R_i = GC_i \times \sum_{j=1}^{J} \frac{C_{ij0}}{WA_{j1}}$
2. Order the airplanes in descending order of the cost ratio.
3. Let p be the priority order of airplanes where the highest cost ratio is p=1 and lowest cost ratio is p= **I**.
4. Use the following algorithm to find AMCA schedule.

Start

For j=1 to J

For k=1 to K

For p=1 to **I**

$W_{pjk} = \min\{C_{pj(k-1)}, WA_{jk}\}$

$C_{pjk} = C_{pj(k-1)} - W_{pjk}$

$WA_{jk} = WA_{jk} - W_{pjk}$

Next p

Next k

Next j

End

Example 6 is solved using the two ratio costs method heuristic. Table 3-4 & Table 3-5 shows the max and total ratio for each airplane, the corresponding costs for each method and the priority order list for the airplanes. The solution using total ratio cost method heuristic is shown in Table 3-6 where the cost is 415338 SR which is higher than the optimal solution by 6.87 %. Using the maximum ratio cost method the cost is found to be 436473 SR which is higher than the optimal solution by 12.31 %. See Table 3-7.

Table 3-4: AMCA Heuristic Methods max and total ratio.

Airplane	$\max_{1\le j\le J}\{\frac{C_{ij0}}{WA_{j1}}\}$	$\sum_{j=1}^{J}\frac{C_{ij0}}{WA_{j1}}$	Max ratio ground cost	Total ratio ground cost
1	3.17	7.21	18775.17	42750.91
2	2.60	7.03	28997.80	78442.77
3	4.44	8.06	15122.64	27465.34
4	4.04	7.37	39983.88	72973.88
5	3.10	7.98	8329.70	21442.26
6	2.04	5.91	5948.64	17223.84
7	3.30	9.13	29990.40	82951.80

Table 3-5: AMCA Heuristic Methods priority order list for example 6.

order using Total Ratio cost method		order using Max Ratio cost method	
Airplane	Cost	Airplane	Cost
7	82951.80	4	39983.88
2	78442.77	7	29990.40
4	72973.88	2	28997.80
1	42750.91	1	18775.17
3	27465.34	3	15122.64
5	21442.26	5	8329.70
6	17223.84	6	5948.64

Table 3-6: AMCA Heuristic Method result for example 6 using total ratio.

		Number of workers assigned at each day																			
Airplane	Jobs	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
7	Avionics	30	30	30	9																
	Power Plant	30	30	19																	
	Airframe	25	25	7																	
	Cabin	32																			
2	Avionics				21	30	27														
	Power Plant			11	8																
	Airframe			18	25	17															
	Cabin	3	35	11																	
4	Avionics						3	21													
	Power Plant				22	18															
	Airframe					8	25	25	25	18											
	Cabin			24	18																
1	Avionics							9	30	30	26										
	Power Plant					12	14														
	Airframe									7	25	1									
	Cabin				17	35	13														
3	Avionics										4	24									
	Power Plant						16	30	15												
	Airframe											24	25	25	25	12					
	Cabin						22	1													
5	Avionics											6	30	30	27						
	Power Plant								15	9											
	Airframe															13	25	25	4		
	Cabin							34	15												
6	Avionics														3	30	9				
	Power Plant									20											
	Airframe																		21	25	5
	Cabin								20	35	8										

Table 3-7: AMCA Heuristic Method result for example 6 using maximum ratio.

		Number of workers assigned at each day																			
Airplane	Jobs	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
4	Avionics	24																			
	Power Plant	30	10																		
	Airframe	25	25	25	25	1															
	Cabin	35	7																		
7	Avionics	6	30	30	30	3															
	Power Plant		20	30	29																
	Airframe					24	25	8													
	Cabin		28	4																	
2	Avionics					27	30	21													
	Power Plant				1	18															
	Airframe							17	25	18											
	Cabin			31	18																
1	Avionics							9	30	30	26										
	Power Plant					12	14														
	Airframe									7	25	1									
	Cabin				17	35	13														
3	Avionics										4	24									
	Power Plant						16	30	15												
	Airframe											24	25	25	25	12					
	Cabin						22	1													
5	Avionics											6	30	30	27						
	Power Plant								15	9											
	Airframe															13	25	25	4		
	Cabin							34	15												
6	Avionics														3	30	9				
	Power Plant									20											
	Airframe																		21	25	5
	Cabin								20	35	8										

CHAPTER 4

Airplane Maintenance Scheduling

4.1 Introduction

This chapter is about airplane maintenance scheduling and it is divided into three sections. The first section contains description and assumptions for the problem. The second section introduces an integer-linear model and the final section is a numerical example to demonstrate how the model works.

4.2 Problem Description and Assumptions

4.2.1 Problem Descriptions

The airplane maintenance center has limited capacity and resources. In order to make the best use of these resources, the airline company should schedule the maintenance check for its airplanes so that there is enough manpower and maintenance slot to perform the maintenance in time. The maintenance of an airplane should not be delayed beyond a specified number of flying hours set by the FAA. Any violation results in financial penalties. The minimum flying hours that is most economical to do the maintenance is called high-time. The high-time is a predefine level of accumulated flying hours that combine a batch of airplane components that need to be maintained. Figure 4-1 shows time limit definition for an airplane where T1 is the time of the last performed maintenance check, T2 is high-time or the time the airplane is ready to go for maintenance, T3 is the time that the next maintenance is performed at and T4 is the time that the airplane cannot fly without performing the maintenance .

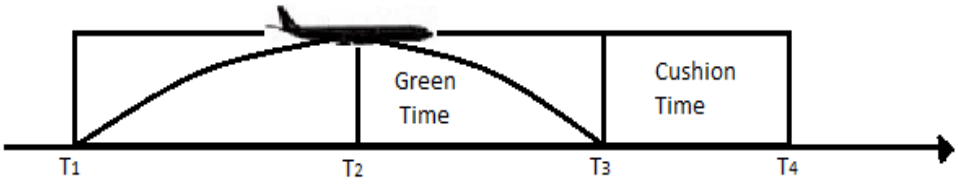

Figure 4-1: Time limit definition for an airplane.

4.2.2 The Assumptions

1- The airplane flying hours for each period are deterministic.

2- The time taken to perform the maintenance is deterministic for each maintenance check.

3- There is only one maintenance center.

4- The maintenance center has fixed capacity slots regardless of maintenance check type.

5- Each airplane could have different flights per day. These form a flying tour. A flying tour starts and ends at the airport that has the maintenance center.

6- The flying hours are assigned to the day where the airplane took off even if the arrival time is on the next day.

4.3 The Integer-Linear Programming Model

4.3.1 The Parameters

i index for the airplane i=1,2,…,I.

m index for number of maintenance m=1,2,…,M.

k index for time period k=1,2,…,K.

ST_i is the flying hours that airplane i have flown before period k =1.

PFR_{ik} is the planned flying hours that airplane i at period k may fly.

M_{im} is the maintenance days required to perform maintenance to airplane i for type m of maintenance.

C_k is the number of maintenance slots available at period k.

UT_i is the maximum legal time that airplane i can fly after the last maintenance.

LT_i is the minimum time required for airplane i to be at high time state "maintenance can be performed to airplane i"

4.3.2 The Decision Variables

x_{ik} is a binary variable. It is 1 if maintenance is being performed and 0 if maintenance is not performed for airplane i at period k.

y_{ikm} is a binary variable. It is set to 1 if maintenance m for airplane i at period k is completed and 0 otherwise.

D_{im} is the time period at which the airplane i has completed maintenance type m.

MT_{im} is the total flying hours that airplane i has flown up to the time the maintenance type m is being performed.

NFT_{im} is the flying hours that airplane i has missed while performing maintenance type m.

4.3.3 Integer- Linear Model

The objective function is to maximize the total flying hours for all airplanes.

$$\text{Max} \sum_{k=M_{im}}^{K} \sum_{k=t-M_{im}+1}^{t} PFR_{ik} \times y_{itm} \qquad (4.1)$$

The next set of equations calculate the sum of hours that airplane i missed while doing maintenance type m.

$$\mathrm{NFRT_{im}} = \sum_{k=M_{im}}^{K} \sum_{k=t-M_{im}+1}^{t} \mathrm{PFR_{ik}} \times \mathrm{y_{itm}}\ ;\ i = 1,2,\dots,I\ and\ m = 1,2,\dots,M \qquad (4.2)$$

The next constraints calculate the total flying hours that airplane i flew up to the time it entered to perform maintenance type m.

$$\mathrm{MT_{im}} = \sum_{t=M_{im}}^{K} (\mathrm{ST_i} + \sum_{k=1}^{t} \mathrm{PFR_{ik}}) \times \mathrm{y_{itm}} - \sum_{\alpha=1}^{m} \mathrm{NFRT_{im}}\ ;\ i = 1,2,\dots,I\ and\ m = 1,2,\dots,M \qquad (4.3)$$

The total flying hours while performing the first maintenance for airplane i must be greater than or high- time and less than or equal the maximum legal flying hours.

$$\mathrm{LT_i} \le \mathrm{MT_{im}} \le \mathrm{UT_i};\qquad \mathrm{i} = 1,2,\dots,\mathrm{I\ and\ m} = 1 \qquad (4.4)$$

The total flying hours while performing maintenance m for airplane i must be greater than or equal high-time and less than or equal the maximum legal flying hours.

$$\mathrm{LT_i} \le \mathrm{MT_{i(m+1)}} - \mathrm{MT_{im}} \le \mathrm{UT_i};\quad \mathrm{i} = 1,2,\dots,\mathrm{I\ and\ m} = 1,2,\dots.,\mathrm{M}-1 \qquad (4.5)$$

The next set of constraints is to assign the maintenance days.

$$\sum_{k=t-M_{im}+1}^{t} \mathrm{x_{ik}} \ge \mathrm{y_{itm}} * \mathrm{M_{im}};\ \mathrm{i} = 1,2,\dots,\mathrm{I}\ ,\mathrm{t} = \mathrm{M_{im}},\dots,\mathrm{K\ and\ m} = 1,2,\dots.,\mathrm{M} \qquad (4.6)$$

The following set of equations set the values of $\mathrm{y_{ikm}}$ to zero because maintenance type m cannot be completed at these periods.

$$y_{ikm} = 0;\ \ i = 1,2, \dots, I\ , k \leq M_{im} - 1 \text{ and } m = 1,2, \dots., M \tag{4.7}$$

The next set computes the period that maintenance type m for airplane i has been completed.

$$D_{im} = \sum_{t=1}^{K} t * y_{itm};\quad i = 1,2, \dots, I \text{ and } m = 1,2, \dots., M \tag{4.8}$$

The next constrains to insure that maintenance type m is done before m+1 to airplane i.

$$D_{im} + 3 \leq D_{i(m+1)};\ \ i = 1,2, \dots., I\ \ \ m = 1,2, \dots, M - 1 \tag{4.9}$$

The total number of airplanes at the maintenance center cannot exceed the number of slots available.

$$\sum_{i} x_{ik} \leq C_k\ ;\quad k = 1,2 \dots, K \tag{4.10}$$

The next constraints insure maintenance type m for airplane i is performed once.

$$\sum_{t=1}^{K} y_{itm} = 1;\quad i = 1,2,3, \dots, I \text{ and } m = 1,2, \dots., M \tag{4.11}$$

In the next section, we illustrate the use of the above model by solving few examples.

4.4 Numerical Examples

In this section , we solved four example that differ in the number of airplanes, length of planning period and the number of maintenance to be performed. Example 1 is presented in this section and the rest are in Appendix A. In Example 1, we solved the AMS problem for twenty airplanes during a planning horizon of ninety days. Table 4-1 shows the maintenance checks M1, M2 and M3 which are the first, second and third maintenance that required to be scheduled in sequence and number under these columns are the days that is needed to perform the maintenance for each airplane. For example, airplane 1 for maintenance M3 requires 2 days to perform the maintenance. Also, Table 4-1 shows the maintenance interval data where ST is the number of flying hours that has already the airplane flew, LT is the minimum flying hours that must be flown before doing maintenance, UT is the maximum flying hours that airplane cannot fly after it before performing the maintenance. Table 4-2 to Table 4-7 are the scheduled flying hours for each airplane and the available maintenance slots for the ninety days. Table 4-8 to Table 4-10 shows the solution for Example 1. For example maintenance M1 for airplane 13 is scheduled at days 26 and 27 and maintenance M2 for airplane 3 is scheduled at day 54.

LINGO 12.0 software package is used on PC with Windows 7 Professional, processor intel (R) core(TM) i5-2500 CPU @ 3.30GHz 3.30 GHz , installed memory (RAM) 8GB and 32-bit operating system to solve these examples. Table 4-11 shows the number of airplanes, variables, integer variables, constraints and elapsed runtime for each example solved.

Example 1

Table 4-1: AMS Example 1 maintenance checks and maintenance interval data.

Airplane	LT	UT	ST	M1	M2	M3
1	100	275	183	1	1	2
2	150	275	232	1	1	1
3	600	800	263	1	1	1
4	100	275	32	2	1	-
5	300	375	144	1	2	1
6	500	600	381	1	1	1
7	500	600	401	1	1	1
8	300	375	244	1	1	1
9	100	275	110	1	1	-
10	500	600	288	1	1	2
11	100	275	258	1	1	1
12	150	275	179	1	1	1
13	600	800	172	2	1	1
14	100	275	162	1	2	-
15	300	375	162	1	1	1
16	500	600	304	1	1	1
17	500	600	192	1	1	1
18	300	375	72	1	1	1
19	100	275	250	1	1	-
20	500	600	22	1	1	-

Table 4-2: AMS problem Example 1 flying hours and maintenance capacity slots from day 1-15.

Airplane\Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	9	8	8	8	8	8	8	9	9	9	8	9	8	8	9
2	8	9	8	9	9	8	9	8	9	8	9	9	9	8	9
3	26	25	24	24	26	24	25	24	25	24	25	25	25	24	26
4	7	6	7	7	7	7	6	7	7	7	7	7	7	7	6
5	12	12	12	12	12	12	12	12	13	12	12	13	13	12	12
6	19	18	17	19	17	17	18	18	19	16	16	19	16	16	19
7	18	20	18	19	19	19	19	18	18	18	20	19	20	20	18
8	13	13	14	14	13	14	12	14	14	12	14	12	13	13	13
9	5	4	6	4	6	5	6	4	4	4	6	5	5	6	4
10	18	19	20	19	16	18	22	24	22	18	21	17	21	22	24
11	9	9	8	8	9	8	9	8	9	9	8	9	9	8	9
12	8	8	8	9	8	8	9	8	9	8	9	9	8	8	9
13	24	26	26	25	24	25	26	24	26	25	26	24	26	25	25
14	7	6	6	6	7	6	6	7	7	7	6	7	7	6	6
15	13	12	12	12	12	13	13	12	13	12	12	13	12	13	12
16	16	17	19	18	18	19	16	17	16	16	18	18	16	19	19
17	18	20	19	20	19	18	20	19	20	19	20	20	19	18	18
18	13	13	13	14	13	13	13	13	14	14	14	12	14	12	12
19	5	6	5	4	4	4	4	6	6	6	6	4	6	4	5
20	17	17	20	20	19	16	18	17	20	24	19	18	17	18	22
Capacity	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2

Table 4-3: AMS problem Example 1 flying hours and maintenance capacity slots from day 16-30.

Airplane\ Day	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	8	9	8	9	8	8	8	8	8	9	8	9	9	9	8
2	8	9	9	8	8	8	8	9	8	8	8	9	9	9	8
3	24	24	26	26	24	26	24	24	26	26	24	24	25	24	26
4	7	6	7	7	6	7	7	7	7	7	6	7	6	7	7
5	13	13	12	13	12	12	12	13	12	12	12	13	13	13	12
6	17	19	16	18	19	17	17	18	18	18	18	16	16	17	17
7	18	19	20	18	18	19	19	20	19	18	18	18	18	19	19
8	12	14	14	14	14	14	14	13	13	13	12	12	14	12	14
9	5	4	6	6	5	4	5	6	4	4	6	5	5	5	6
10	20	17	24	17	21	20	17	19	24	23	23	18	24	23	23
11	9	8	8	8	8	8	8	8	8	9	8	9	9	9	8
12	8	8	8	8	8	8	9	8	8	9	8	9	8	9	9
13	26	24	25	25	25	24	25	26	25	24	25	24	24	25	25
14	7	6	7	6	7	7	7	6	6	6	6	7	6	7	7
15	13	12	12	12	13	13	13	12	12	12	13	12	12	13	13
16	17	19	18	18	17	19	16	19	17	16	17	16	18	17	18
17	19	20	20	20	19	20	18	19	19	19	18	19	19	20	19
18	14	14	12	14	12	13	13	14	13	13	12	12	13	13	13
19	4	6	5	6	5	6	5	4	5	4	4	4	5	5	4
20	20	21	20	19	18	23	24	18	18	21	24	17	16	21	22
Capacity	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2

Table 4-4: AMS problem Example 1 flying hours and maintenance capacity slots from day 31-45.

Airplane\ Day	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
1	8	9	9	8	8	8	9	9	8	8	9	8	8	8	8
2	8	8	9	9	8	9	9	9	9	8	9	9	9	8	9
3	26	25	25	25	26	26	26	24	25	24	26	24	24	25	24
4	6	7	6	6	7	7	7	7	6	6	7	7	6	6	7
5	13	13	12	13	12	13	12	12	12	12	13	13	12	12	13
6	18	18	16	18	16	16	17	16	16	16	17	16	16	18	18
7	19	19	20	20	20	19	19	19	20	20	20	19	19	20	18
8	13	14	12	14	14	14	14	13	14	12	12	12	13	12	13
9	5	5	5	5	6	4	6	5	4	6	6	6	4	4	6
10	24	19	21	24	17	23	21	23	19	20	17	23	17	23	20
11	9	9	8	9	9	8	9	8	9	8	8	9	9	9	9
12	8	9	9	9	9	9	8	8	9	9	9	9	9	9	8
13	24	25	26	25	25	25	24	24	24	26	24	24	25	26	26
14	6	7	6	6	7	7	7	7	7	6	7	7	7	6	7
15	12	13	13	13	13	13	13	13	13	12	12	12	13	12	13
16	19	19	19	19	18	18	16	17	18	18	16	17	18	16	19
17	19	20	20	19	18	20	18	20	20	18	18	19	19	20	19
18	13	12	13	13	12	12	13	14	13	13	14	12	12	13	12
19	4	5	6	4	5	4	4	4	6	5	5	4	6	4	4
20	17	21	21	22	22	22	22	16	24	18	17	22	23	23	16
Capacity	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2

Table 4-5: AMS problem Example 1 flying hours and maintenance capacity slots from day 46-60.

Airplane\ Day	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
1	9	8	9	9	8	8	8	9	8	9	8	9	8	9	8
2	8	8	8	9	8	9	9	9	9	9	8	8	8	9	9
3	25	26	25	24	25	26	25	24	25	25	25	25	24	26	24
4	7	7	7	6	7	6	7	7	7	7	6	7	6	6	7
5	12	13	13	13	12	13	13	12	12	12	12	12	13	13	13
6	16	18	19	18	17	16	16	16	17	16	17	17	16	17	19
7	19	19	19	18	18	18	20	19	19	20	20	20	19	19	18
8	13	14	13	13	13	14	12	14	12	12	14	12	13	13	13
9	4	4	5	5	4	6	4	6	4	6	5	4	4	6	4
10	20	18	18	17	18	16	23	17	24	21	18	20	19	18	24
11	9	8	8	9	8	9	8	8	9	9	9	8	9	9	9
12	9	9	8	8	8	8	9	9	9	9	9	8	8	9	9
13	24	26	26	24	26	26	25	26	26	26	25	26	25	25	24
14	6	6	7	6	6	7	7	7	6	7	6	6	7	6	7
15	13	13	12	12	12	12	13	12	13	13	12	13	12	12	12
16	16	16	17	18	16	19	17	16	19	19	17	16	17	19	17
17	20	20	20	18	20	18	19	20	19	20	18	18	19	18	19
18	12	12	12	12	12	13	13	12	12	14	14	14	13	13	14
19	5	5	5	4	4	5	5	4	4	5	6	6	5	4	4
20	22	18	18	23	17	21	16	18	23	17	24	23	18	21	17
Capacity	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2

Table 4-6: AMS problem Example 1 flying hours and maintenance capacity slots from day 61-75.

Airplane\ Day	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75
1	9	8	9	8	9	9	8	9	9	9	8	9	8	9	8
2	9	8	8	9	8	8	9	8	9	8	8	9	8	8	9
3	24	25	24	24	24	25	26	25	25	26	25	26	24	24	26
4	6	7	7	7	6	7	7	6	6	7	6	6	6	6	7
5	13	13	13	13	12	12	12	13	12	12	13	12	13	12	12
6	19	18	16	19	19	16	19	17	19	18	17	19	17	17	17
7	20	20	20	20	19	18	20	20	18	20	20	20	20	19	20
8	12	14	13	14	12	13	13	14	12	14	14	14	12	14	14
9	6	4	5	6	5	6	4	6	6	6	5	4	6	4	4
10	19	22	16	17	21	21	21	21	19	21	17	17	21	19	22
11	8	8	8	8	9	9	8	9	9	8	8	9	9	9	8
12	9	8	8	9	8	9	8	9	8	9	9	9	9	9	8
13	25	25	26	24	24	25	24	24	26	26	25	24	24	24	26
14	7	7	6	7	6	7	7	7	6	7	6	6	6	6	7
15	12	13	12	13	12	12	12	12	12	12	12	13	13	13	13
16	16	19	17	17	18	17	19	18	18	18	16	17	17	16	17
17	19	18	18	19	18	19	19	18	20	19	19	18	18	20	18
18	13	14	13	13	13	14	14	14	13	13	14	12	13	12	12
19	4	6	4	5	5	5	6	4	5	5	5	6	6	6	6
20	21	18	24	20	17	17	23	19	17	20	18	19	17	21	16
Capacity	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2

Table 4-7: AMS problem Example 1 flying hours and maintenance capacity slots from day 76-90.

Airplane\ Day	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
1	9	9	8	8	9	9	8	9	9	8	8	9	8	9	9
2	9	9	9	9	9	8	9	8	9	9	9	9	8	8	8
3	26	26	24	24	24	24	26	24	26	25	24	24	26	26	25
4	6	7	7	7	6	6	6	7	7	6	7	6	6	7	6
5	13	12	13	12	13	12	13	13	13	12	12	13	12	13	13
6	17	16	19	18	17	17	18	17	19	19	17	18	17	16	16
7	18	18	18	20	19	20	18	20	18	20	20	19	20	19	18
8	13	14	14	13	12	13	13	13	13	13	14	12	14	13	14
9	6	5	6	6	6	6	6	6	4	4	6	4	6	4	4
10	18	17	18	20	20	19	19	17	19	21	17	17	17	20	22
11	9	8	8	9	8	8	9	9	9	9	9	8	9	8	9
12	8	8	8	9	9	9	8	8	9	9	9	8	9	8	9
13	24	25	24	24	26	25	24	26	26	26	24	24	25	25	25
14	7	6	6	6	6	7	7	6	6	7	6	6	7	6	6
15	12	12	13	13	13	13	12	13	12	12	12	12	13	12	12
16	19	18	19	18	16	16	18	19	19	17	18	18	18	18	17
17	19	18	18	20	19	19	19	20	19	18	18	19	18	18	20
18	12	13	13	13	13	14	13	12	12	13	12	14	14	13	14
19	6	4	5	5	6	4	5	6	5	4	6	4	6	6	6
20	18	17	20	16	22	16	19	20	21	20	18	21	22	17	18
Capacity	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2

Table 4-8: Solution for AMS problem Example 1 from day 1 to 30.

Airplane\Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1												M1																		
2						M1																								
3																						M1								
4																														
5																			M1											
6													M1																	
7											M1																			
8										M1																				
9																														
10																M1														
11		M1																												
12												M1																		
13																										M1	M1			
14																		M1												
15																		M1												
16																M1														
17																						M1								
18																								M1						
19						M1																								
20																														M1

Table 4-9: Solution for AMS problem Example 1 from day 31 to 60.

Airplane\Day	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
1													M2																	
2								M2																						
3																								M2						
4						M1	M1																							
5																			M2	M2										
6																		M2												
7												M2																		
8								M2																						
9				M1																										
10														M2																
11				M2																										
12														M2																
13																										M2				
14																													M2	
15																	M2													
16																					M2									
17																							M2							
18																							M2							
19																														
20																													M2	

Table 4-10: Solution for AMS problem Example 1 from day 61 to 90.

Airplane\Day	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
1															M3	M3														
2										M3																				
3																									M3					
4														M2																
5																			M3											
6																						M3								
7													M3																	
8							M3																							
9											M2																			
10														M3	M3															
11						M3																								
12																M3														
13																													M3	
14	M2																													
15																	M3													
16																									M3					
17																								M3						
18																					M3									
19			M2																											
20																														

Table 4-11: Model information for AMS problems solved.

Example	Number of Airplanes	Number of Variables	Number of Integer Variables	Number of Constraints	Runtime (h,mm,ss)
1	20	7380	7200	5885	0:00:03
2	30	18360	18000	15233	0:00:12
3	40	30480	30000	25219	0:00:46
4	50	54750	54000	46866	0:03:58
-	100	183700	182500	149042	0:11:10

CHAPTER 5

Airplane Maintenance Scheduling With Maintenance Crew Assignment

5.1 Introduction

In Chapter 3, we solved the problem of assigning maintenance crew to perform maintenance on airplane. In Chapter 4, we assign the maintenance days to the airplanes. This chapter is about airplane maintenance scheduling with maintenance crew assignment. We find the maintenance days for airplane and assign the crew. Solving the combined problem will result in a nonlinear integer program which is difficult to solve. There for, we design a heuristic algorithm to solve the problem. The chapter is divided into three sections. The first section contains the description and assumptions for the problem. The second section presents a heuristic approach used to solve the problem and the final section contains a numerical example to demonstrate how the model works.

5.2 Problem Description and Assumptions

5.2.1 Problem Description

The problem is a combination of both Chapter 3 and Chapter 4 problems, where we have a set of airplanes that have fixed flying schedule and set of maintenance checks. Each maintenance check has different jobs that require given man-day or man-shift in order to be completed. The objective is to find best airplane maintenance schedule that minimize ground cost of the airplanes.

5.2.2 The Assumptions

1- The airplane flying hours for each period are deterministic

2- The maintenance center has fixed number of slots regardless of maintenance check type.

3- There is one maintenance center.

4- Each airplane could have different flights per day. These form a flying tour. A flying tour start and ends at the airport that has the maintenance center.

5- The flying hours are assigned to the day where the airplane took off even if the arrival time is on the next day.

6- The time taken to finish the job is deterministic.

7- The number of workers for each job is deterministic.

8- Assigned workers cannot be shifted or moved to another airplane until the assigned period ends.

9- The job required for airplane can be performed in separated periods.

10- Workers are specialized in one type of job.

5.3 The Heuristic Algorithm

Step 1: Calculate the period it takes to finish each maintenance type M_{im} if the entire workers assigned to that maintenance.

$$M_{im} = \max_{1 \le j \le J} \{ \left\lceil \frac{C_{ij0}^{m}}{WA_{j1}} \right\rceil \}$$

Where $\lceil x \rceil$ is the smallest integer $\geq$ x

Step 2: Using $ST_i, PFR_{ik}, M_{im}, C_k, UT_i, LT_i$ and PFR_{ik} , generate AMS using Model 2 in Chapter 4. If the problem is feasible go to Step 3. Otherwise stop and use best solution founded so far.

Step 3: From the AMS generated from Step 2, we will identify the start and end period for each maintenance check for each airplane.

f is the end period of maintenance

s is the start period of the maintenance

$$f = D_{im} \tag{5.1}$$

$$s = D_{im} - M_{im} + 1 \tag{5.2}$$

We will use model 1 AMCA to assign workers. Assuming that each maintenance check is a separate airplane and workers W_{ijk} will be assigned in period $\geq s$. The following set of constraints will perform this requirement

$$W_{ijk} = 0; for\ i = 1,2,\cdots,I, j = 1,2\cdots,J\ and\ k \leq s - 1 \tag{5.1}$$

Step 4: Save the best solution generated so far to be compared with future solutions.

Step 5: Check the AMCA schedule with AMS for each airplane as shown in step 6,7 and 8. Start with the first maintenance check then the next and so. This is because any change in a maintenance check periods might affect subsequent checks.

Step 6: if $W_{ijk} > 0\ whenever\ \ x_{ik} = 1\ and\ W_{ijk} = 0\ \ whenever x_{ik} = 0$, stop and report the solution.

Step 7: if $COM_{im} > f, set\ M_{im} = M_{im} + COM_{im} - f$ and go to Step 2.

Step 8: If $W_{ijk} = 0\ and\ x_{ik} = 1$, then the maintenance crew has been assigned later than it should:

A. Check if $\sum_i^I \mathrm{x_{ik}} < C_k\ , for\ s - M_{im} \leq k \leq s - 1$. Then set $s = \ s - M_{im}$ and go to Step 3, else

B. Let N be the number of airplanes for which $W_{ijk} > 0\ whenever\ \ x_{ik} = 1\ \ for\ s \leq k \leq f$. Set $\ C_k = N; for\ s \leq k \leq f$ and go to Step 2.

5.4 Numerical Examples

We have solved two examples. Example 1 is presented in this section and Example 2 in the appendix A. Example 1 has 10 airplanes, some of which require one maintenance check and some require two maintenance checks during a period of 60 days. Example 2 has 20 airplanes, , some of which require two maintenance checks and some require three maintenance checks during the next 90 days. Table 5-1 & Table 5-2 are the daily flying hours and available slots for maintenance. Table 5-3 shows the maintenance interval data. In Table 5-3, ST is the number of flying hours that have already been flown by each airplane, LT is the minimum flying hours that must be flown before performing maintenance and UT is the maximum flying hours that an airplane cannot fly after it without performing due maintenance. Table 5-4 contains the required man-day for each job for each maintenance check. Step 1 of the heuristic algorithm results in the maintenance schedule shown in Table 5-5. It shows the required days to complete the maintenance checks. Step 2 gives the AMS in Table 5-6 & Table 5-8. Step3 results in the AMCA for the problem, as shown in Table 5-7 & Table 5-9. Table 5-8, shows that the

maintenance M2 for Airplane 8 is scheduled at day 38 (f =38), however, in Table 5-9 the workers took two days (day 38 & 39 and $COM_{82} = 39$) to complete the maintenance. In Step 7, we compute $M_{82} = 1 + 39 - 38 = 2$. The problem resolved in Step 2 with M_{82} =2 and we get AMS exactly as in Table 5-6. Table 5-10 shows that the maintenance M2 for airplane 8 will take place in days 38 & 39. Performing Step3 again, we will get AMCA schedule that is the same as in the previous solution, hence we stop.

Table 5-1: AMS with AMCA problem Example 1 flying hours and maintenance capacity slots from day 1 to 30.

Airplane\Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	9	8	8	8	8	8	8	9	9	9	8	9	8	8	9	8	9	8	9	8	8	8	8	8	9	8	9	9	9	8
2	8	9	8	9	9	8	9	8	9	8	9	9	9	8	9	8	9	9	8	8	8	8	9	8	8	8	9	9	9	8
3	26	25	24	24	26	24	25	24	25	24	25	25	25	24	26	24	24	26	26	24	26	24	24	26	26	24	24	25	24	26
4	7	6	7	7	7	7	6	7	7	7	7	7	7	7	6	7	6	7	7	6	7	7	7	7	7	6	7	6	7	7
5	12	12	12	12	12	12	12	12	13	12	12	13	13	12	12	13	13	12	13	12	12	12	13	12	12	12	13	13	13	12
6	19	18	17	19	17	17	18	18	19	16	16	19	16	16	19	17	19	16	18	19	17	17	18	18	18	18	16	16	17	17
7	18	20	18	19	19	19	19	18	18	18	20	19	20	20	18	18	19	20	18	18	19	19	20	19	18	18	18	18	19	19
8	13	13	14	14	13	14	12	14	14	12	14	12	13	13	13	12	14	14	14	14	14	14	13	13	13	12	12	14	12	14
9	5	4	6	4	6	5	6	4	4	4	6	5	5	6	4	5	4	6	6	5	4	5	6	4	4	6	5	5	5	6
10	18	19	20	19	16	18	22	24	22	18	21	17	21	22	24	20	17	24	17	21	20	17	19	24	23	23	18	24	23	23
Capacity	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2

Table 5-2: AMS with AMCA problem Example 1 flying hours and maintenance capacity slots from day 31 to 60.

Airplane\Day	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
1	8	9	9	8	8	8	9	9	8	8	9	8	8	8	8	9	8	9	9	8	8	8	9	8	9	8	9	8	9	8
2	8	8	9	9	8	9	9	9	9	8	9	9	9	8	9	8	8	8	9	8	9	9	9	9	9	8	8	8	9	9
3	26	25	25	25	26	26	26	24	25	24	26	24	24	25	24	25	26	25	24	25	26	25	24	25	25	25	25	24	26	24
4	6	7	6	6	7	7	7	7	6	6	7	7	6	6	7	7	7	7	6	7	6	7	7	7	7	6	7	6	6	7
5	13	13	12	13	12	13	12	12	12	12	13	13	12	12	13	12	13	13	13	12	13	13	12	12	12	12	12	13	13	13
6	18	18	16	18	16	16	17	16	16	16	17	16	16	18	18	16	18	19	18	17	16	16	16	17	16	17	17	16	17	19
7	19	19	20	20	20	19	19	19	20	20	20	19	19	20	18	19	19	19	18	18	18	20	19	19	20	20	20	19	19	18
8	13	14	12	14	14	14	14	13	14	12	12	12	13	12	13	13	14	13	13	13	14	12	14	12	12	14	12	13	13	13
9	5	5	5	5	6	4	6	5	4	6	6	6	4	4	6	4	4	5	5	4	6	4	6	4	6	5	4	4	6	4
10	24	19	21	24	17	23	21	23	19	20	17	23	17	23	20	20	18	18	17	18	16	23	17	24	21	18	20	19	18	24
Capacity	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2

Table 5-3: AMS with AMCA problem Example 1 maintenance interval data.

Airplane	LT	UT	ST
1	100	275	183
2	150	275	232
3	600	800	263
4	100	275	32
5	300	375	144
6	500	600	381
7	500	600	401
8	300	375	244
9	100	275	110
10	500	600	288

Table 5-4: AMS with AMCA problem Example 1 man-day required to complete maintenance checks for the airplanes.

			Man-day required to complete the job			
Aircraft	Maintenance Check	Ground time cost SR/Day	Avionics	Power Plant	Airframe	Cabin
1	M1	5567	37	24	25	28
1	M2	5567	20	17	20	25
2	M1	11565	30	26	22	24
2	M2	11565	29	23	25	21
3	M1	5108	43	65	42	51
3	M2	5108	14	13	17	15
4	M1	2294	19	15	13	16
5	M1	7270	27	25	22	15
5	M2	7270	34	42	59	42
6	M1	9949	20	28	23	30
6	M2	9949	46	35	30	63
7	M1	3281	19	10	18	15
7	M2	3281	25	25	30	22
8	M1	7105	32	29	25	19
8	M2	7105	20	17	30	24
9	M1	4182	23	27	20	15
10	M1	11963	25	25	20	31
10	M2	11963	41	22	25	30
Number of workers available			40	35	30	35

Table 5-5: AMS with AMCA problem Example 1 maintenance checks data*.

Airplane	M1	M2
1	1	1
2	1	1
3	2	1
4	1	-
5	1	2
6	1	2
7	1	1
8	1	1
9	1	-
10	1	2

*M1 and M2 are the maintenance need to be done in sequence.

Solution for Example 1

Table 5-6: Solution for AMS with AMCA Example 1 airplane maintenance schedule from day 1 to 30.

Airplane\Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1												M1																		
2						M1																								
3																						M1	M1							
4																														
5																			M1											
6													M1																	
7											M1																			
8										M1																				
9																														
10																M1														

Table 5-7: Solution for AMS with AMCA Example 1 maintenance crew working schedule from day 1 to 30.

	Aircrafts\Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	Avionics												37																	
	Power Plant												24																	
	Airframe												25																	
	Cabin												28																	
2	Avionics						30																							
	Power Plant						26																							
	Airframe						22																							
	Cabin						24																							
3	Avionics																						40	3						
	Power Plant																						35	30						
	Airframe																						30	12						
	Cabin																						35	16						
4	Avionics																													
	Power Plant																													
	Airframe																													
	Cabin																													
5	Avionics																			27										
	Power Plant																			25										
	Airframe																			22										
	Cabin																			15										
6	Avionics													20																
	Power Plant													28																
	Airframe													23																
	Cabin													30																
7	Avionics											19																		
	Power Plant											10																		
	Airframe											18																		
	Cabin											15																		
8	Avionics										32																			
	Power Plant										29																			
	Airframe										25																			
	Cabin										19																			
9	Avionics																													
	Power Plant																													
	Airframe																													
	Cabin																													
10	Avionics															25														
	Power Plant															25														
	Airframe															20														
	Cabin															31														

Table 5-8: Solution for AMS with AMCA Example 1 airplane maintenance schedule from day 31 to 60.

Airplane\Day	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
1														M2																
2								M2																						
3																								M2						
4							M1																							
5																			M2	M2										
6																		M2	M2											
7												M2																		
8								M2																						
9			M1																											
10														M2	M2															

Table 5-9: Solution for AMS with AMCA Example 1 maintenance crew working schedule from day 31 to 60.

	Aircrafts\Day	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
1	Avionics														20																
	Power Plant														17																
	Airframe														20																
	Cabin														25																
2	Avionics								29																						
	Power Plant								23																						
	Airframe								25																						
	Cabin								21																						
3	Avionics																							14							
	Power Plant																							13							
	Airframe																							17							
	Cabin																							15							
4	Avionics							19																							
	Power Plant							15																							
	Airframe							13																							
	Cabin							16																							
5	Avionics																			34											
	Power Plant																			35	7										
	Airframe																			30	29										
	Cabin																			7	35										
6	Avionics																		40	6											
	Power Plant																		35												
	Airframe																		30												
	Cabin																		35	28											
7	Avionics												25																		
	Power Plant												25																		
	Airframe												30																		
	Cabin												22																		
8	Avionics								11	9																					
	Power Plant								12	5																					
	Airframe								5	25																					
	Cabin								14	10																					
9	Avionics				23																										
	Power Plant				27																										
	Airframe				20																										
	Cabin				15																										
10	Avionics														20	21															
	Power Plant															22															
	Airframe														10	15															
	Cabin															30															

Table 5-10: Solution for AMS with AMCA Example 1 airplane maintenance schedule from day 31 to 60.

Airplane\Day	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
1														M2																
2								M2																						
3																								M2						
4							M1																							
5																			M2	M2										
6																		M2	M2											
7												M2																		
8								M2	M2																					
9				M1																										
10														M2	M2															

CHAPTER 6

Conclusion and Future Research

6.1 Introduction

In this chapter we summaries the work done in this thesis and suggest some research to be done in the future.

6.2 Summary

In this thesis, airplane maintenance scheduling with maintenance crew assignment have been studied as separate problems; maintenance crew assignment problem in Chapter three and airplane maintenance scheduling in Chapter four and as one problem in Chapter five.

In the maintenance crew assignment problem, the airplane maintenance check requires manpower per period for different jobs or activities in order to be performed and only workers specialized in that kind of job can do the work. The objective is to minimize the total ground cost for all the airplanes. The problem is modeled as an MILP. Different examples are solved.

The airplane maintenance scheduling problem in this thesis assumes that airplanes follow fixed flying schedule and maintenance checks can be done within known interval of flying hours where the maintenance center has available capacity slots. The objective is to schedule the airplane maintenance checks while maximizing the total flying hours.

The problem is modeled as an integer-linear model. Different examples are solved to illustrate how the model works.

In Chapter five, airplane maintenance scheduling with maintenance crew assignment, combines the two problems where a heuristic approach which uses the MILP models from maintenance crew assignment and airplane maintenance scheduling are used to solve the problem. Two examples are solved to demonstrate how it works.

6.3 Possible Extensions to the Models

For maintenance crew assignment model, possible extensions include:

1- Changing the objective function to include start and end period of work in the airplane.
2- Changing the assumptions to include multiple activity workers

For airplane maintenance scheduling model, possible extensions or implementations includes:

1- Using real data where the objective is to find maintenance schedule with less maintenance checks during holiday seasons.
2- Drop the assumption that a flying tour starts and ends at the airport that has the maintenance center.
3- Having multiple maintenance centers.

For airplane maintenance scheduling with crew assignment, possible extensions or implementations include:

1- Testing the model with real life data
2- Updating the model to fit other applications, e.g. for factory that has multiple production lines and preventive maintenance is done after certain hours of production and the objective is to find a maintenance schedule that keeps some production lines running within one or multiple levels of production while doing maintenance for other production lines.

Appendix A

Airplane Maintenance Crew Assignment example 1 to 5

Table 1: AMCA problem example 1 with two airplanes.

Example1	Man-day needed to complete the job				Ground time cost SR/day
Aircrafts\jobs	Avionics	Power Plant	Airframe	Cabin	
1	49	62	49	65	14898
2	66	90	59	16	3799
Number of worker available	30	30	25	35	

Table 2: Solution for AMCA problem example 1 with two airplanes.

		Number of workers assigned at each day					
Airplane	job\day	1	2	3	4	5	6
1	Avionics	19		30			
	Power Plant	2	30	30			
	Airframe	24	25				
	Cabin	30		35			
2	Avionics	11			30	24	1
	Power Plant	28			30	30	2
	Airframe	1		25	25	8	
	Cabin		15				1

Table 3: AMCA problem example 2 with three airplanes.

Example2	Man-day needed to complete the job				Ground time cost SR/ Day
Aircrafts	Avionics	Power Plant	Airframe	Cabin	
1	27	52	54	24	6837
2	43	70	100	30	11660
3	74	83	77	24	5530
Number of worker available	30	30	25	35	

Table 4: Solution for AMCA example 2 with three airplanes.

		Number of workers assigned at each day									
Airplane	job\day	1	2	3	4	5	6	7	8	9	10
1	Avionics		17	9	1						
	Power Plant		20		1	30		1			
	Airframe					25	6	23			
	Cabin	5	18					1			
2	Avionics	30	13								
	Power Plant	30	10	30							
	Airframe	25	25	25	25						
	Cabin	29			1						
3	Avionics				29		30		14		1
	Power Plant				22		30		30		1
	Airframe							2	25	25	25
	Cabin	1	17	5						1	

Table 5: AMCA problem example 3 with four airplanes.

Example3	Man-day needed to complete the job				Ground time cost SR/Day
Aircrafts	Avionics	Power Plant	Airframe	Cabin	
1	91	87	97	48	3335
2	86	85	41	55	11722
3	85	70	66	55	5451
4	98	23	111	27	5853
Number of worker available	30	30	25	35	

Table 6: Solution for AMCA problem example 3 with four airplanes.

		Number of workers assigned at each day												
Airplane	job\day	1	2	3	4	5	6	7	8	9	10	11	12	13
1	Avionics									1	30	30	30	
	Power Plant										30	30		27
	Airframe			7							15	25	25	25
	Cabin			35	12				1					
2	Avionics	30	26	30										
	Power Plant	25	30	30										
	Airframe	16	25											
	Cabin	20	35											
3	Avionics		4		30	21	30							
	Power Plant	5			28	7	30							
	Airframe	9		7	25	25								
	Cabin	15			5	35								
4	Avionics					9		30	30	29				
	Power Plant					23								
	Airframe			11			25	25	25	25				
	Cabin									27				

Table 7: AMCA problem example 4 with five airplanes.

Example4	Man-day needed to complete the job				Ground time cost SR/Day
Aircrafts	Avionics	Power Plant	Airframe	Cabin	
1	97	29	46	90	13460
2	21	15	34	41	11999
3	20	81	98	57	14954
4	61	44	75	47	11741
5	95	55	31	36	7227
Number of worker available	30	30	25	35	

Table 8: Solution for AMCA problem example 4 with five airplanes

		Number of workers assigned at each day											
Airplane	job\day	1	2	3	4	5	6	7	8	9	10	11	12
1	Avionics	30	7	30	30								
	Power Plant	5	15	8	1								
	Airframe	16		5	25								
	Cabin	20		35	35								
2	Avionics		21										
	Power Plant		15										
	Airframe	9	25										
	Cabin	14	27										
3	Avionics						20						
	Power Plant			22	16			30	13				
	Airframe			20		25	25	8	20				
	Cabin	1	1			6	35	14					
4	Avionics							1		30	30		
	Power Plant				13		30			1			
	Airframe									11	14	25	25
	Cabin								35				12

Table 9: AMCA problem example 5 with six airplanes.

Example5	Man-day needed to complete the job				Ground time cost SR/Day
Aircrafts	Avionics	Power Plant	Airframe	Cabin	
1	30	89	63	88	7565
2	63	38	53	30	11499
3	25	83	67	75	5825
4	70	20	70	81	12962
5	77	46	45	81	2732
6	42	66	44	25	3836
Number of worker available	30	30	25	35	

Table 10: Solution for AMCA problem example 5 with six airplanes.

		Number of workers assigned at each day													
Airplane	Jobs	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Avionics								30						
	Power Plant			12		26	30	30							
	Airframe						25	25	13						
	Cabin					34	35	19							
2	Avionics			20	30	13									
	Power Plant	10	28												
	Airframe			5	23	25									
	Cabin				30										
3	Avionics							25							
	Power Plant										30	23	30		
	Airframe				2				12	3		25	25		
	Cabin							16	35	24					
4	Avionics	30	30	10											
	Power Plant	20													
	Airframe	25	25	20											
	Cabin	35	35	11											
5	Avionics									17	30	30			
	Power Plant			16	30										
	Airframe									3				25	17
	Cabin									11	35	35			
6	Avionics					17	25								
	Power Plant		2			4			30	30					
	Airframe									19	25				
	Cabin			20	5										

Airplane Maintenance Scheduling Example 2 to 4

Example 2

Table 11: AMS Example 2 maintenance checks and maintenance interval data.

Airplane	LT	UT	ST	M1	M2	M3	M4
1	300	375	197	1	1	1	-
2	300	375	87	1	1	-	-
3	700	1000	769	1	1	1	-
4	150	275	79	1	1	1	-
5	400	600	247	2	1	-	-
6	600	750	671	1	1	1	-
7	400	600	546	1	1	1	1
8	400	600	244	1	1	1	-
9	150	275	10	1	2	-	-
10	600	750	201	1	1	2	-
11	300	375	58	1	1	-	-
12	300	375	301	1	1	1	-
13	700	1000	597	1	2	1	-
14	150	275	184	1	1	1	-
15	400	600	495	2	1	1	-
16	600	750	705	1	1	1	-
17	600	750	46	1	1	1	-
18	400	600	321	1	2	1	-
19	150	275	156	1	1	-	-
20	600	750	413	1	1	1	-
21	300	375	168	1	1	1	-
22	300	375	24	1	1	-	-
23	700	1000	818	1	2	1	-
24	150	275	260	1	1	1	-
25	300	375	329	1	1	1	1
26	600	750	441	1	1	1	-
27	600	750	742	1	1	1	2
28	300	375	33	1	1	1	1
29	150	275	137	1	1	-	-
30	600	750	49	1	1	1	-

Table 12: AMS problem Example 2 flying hours and maintenance capacity slots from day 1 to 15.

Airplane\Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	8	9	9	8	9	9	9	9	9	8	9	9	8	9	9
2	8	9	9	8	8	8	8	9	8	8	9	9	9	8	9
3	24	26	25	26	25	26	24	24	26	25	26	25	26	25	26
4	6	6	6	7	6	6	7	6	6	7	6	6	7	7	6
5	13	12	13	12	12	13	13	13	13	12	13	12	13	13	12
6	19	19	18	16	17	19	17	17	17	16	19	18	17	17	18
7	19	19	18	19	18	20	18	20	18	20	20	18	19	18	18
8	14	13	12	14	13	13	12	13	13	12	14	14	12	14	14
9	5	6	6	6	4	5	4	5	6	6	5	6	4	6	4
10	20	17	17	22	18	21	21	20	19	17	19	17	18	20	20
11	9	8	9	8	9	8	8	8	9	9	9	8	9	9	8
12	8	9	9	8	8	9	9	9	8	8	8	8	9	9	9
13	26	26	26	25	26	25	25	26	26	24	26	26	25	26	25
14	6	6	7	6	7	6	6	6	7	6	6	6	7	6	7
15	13	12	13	12	13	13	13	13	13	13	13	13	13	13	13
16	16	17	18	16	17	16	17	16	16	19	16	16	19	18	18
17	18	20	18	18	20	20	18	19	18	18	19	20	20	20	19
18	14	13	13	14	12	13	13	13	14	12	12	13	13	12	14
19	6	4	4	6	4	6	6	4	5	5	5	5	4	6	4
20	24	19	22	24	23	20	19	22	23	20	17	19	22	20	18
21	9	9	9	9	8	8	9	8	8	9	8	9	8	9	9
22	9	8	9	8	9	8	9	9	8	8	8	8	8	8	8
23	25	25	25	25	25	26	25	26	26	26	24	25	26	24	24
24	7	6	6	6	6	7	7	6	7	6	6	7	7	7	7
25	13	13	12	13	12	12	12	13	12	13	12	13	13	12	13
26	18	17	16	18	19	16	17	17	17	17	19	16	16	17	19
27	19	18	20	20	19	20	18	18	19	18	18	19	20	19	20
28	14	14	12	13	14	14	14	14	14	12	14	12	14	13	14
29	4	4	6	5	6	5	4	5	4	5	4	6	4	5	4
30	23	17	19	18	18	19	21	22	22	16	16	22	22	20	20
Capacity	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4

Table 13: AMS problem Example 2 flying hours and maintenance capacity slots from day 16 to 30.

Airplane\Day	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	9	8	8	9	8	9	9	8	9	8	9	8	9	9	9
2	9	9	9	9	8	8	8	8	9	8	8	8	9	8	9
3	24	25	24	26	26	25	26	26	24	25	25	26	26	26	25
4	7	7	6	6	7	7	6	7	6	7	7	7	7	6	6
5	12	12	13	12	13	13	12	12	13	13	12	13	13	13	13
6	19	18	17	17	19	16	17	16	16	18	18	19	17	19	19
7	19	20	18	18	19	18	18	19	20	20	20	19	20	19	18
8	14	14	12	13	13	12	13	13	14	14	12	14	12	13	13
9	6	6	4	6	6	5	4	5	4	4	4	5	6	5	6
10	22	21	19	18	21	20	19	19	23	19	18	24	20	24	17
11	8	8	8	9	9	9	8	9	8	9	8	8	8	9	9
12	9	8	8	9	9	9	9	9	8	8	8	9	9	8	8
13	26	26	25	25	25	25	24	26	26	26	26	25	26	26	26
14	7	7	7	7	7	7	6	6	6	7	7	7	7	7	7
15	13	13	12	12	12	12	12	12	13	12	12	13	12	13	13
16	16	18	19	18	19	18	17	18	16	16	18	18	18	16	19
17	19	18	20	19	20	19	19	18	20	20	19	20	18	19	20
18	14	14	13	14	12	12	12	14	12	13	12	12	14	12	13
19	5	6	4	6	5	4	5	4	4	4	4	6	5	6	6
20	22	24	18	17	23	20	24	18	24	23	22	22	22	23	22
21	9	8	8	9	8	8	9	8	8	9	8	9	9	9	8
22	9	8	8	8	9	8	9	8	8	8	9	8	9	8	8
23	24	24	25	26	26	25	26	26	26	25	26	26	25	24	25
24	7	7	6	7	7	7	6	7	6	6	6	6	7	6	6
25	12	12	13	12	12	13	12	12	12	12	12	12	12	12	12
26	19	17	19	17	18	18	17	18	17	18	19	16	17	16	16
27	19	20	18	20	20	20	19	20	19	18	18	19	18	18	18
28	13	12	12	12	12	13	14	13	12	13	13	14	14	12	12
29	4	5	6	4	4	6	4	6	6	4	4	6	4	6	4
30	19	18	16	16	22	16	19	24	17	20	16	19	20	22	16
Capacity	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4

Table 14: AMS problem Example 2 flying hours and maintenance capacity slots from day 31 to 45.

Airplane\Day	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
1	9	9	8	8	9	9	8	9	8	8	9	8	9	8	8
2	9	9	9	8	9	8	8	9	9	8	8	9	9	8	8
3	26	26	26	25	25	26	25	24	25	26	24	26	25	25	25
4	7	6	7	6	7	6	7	6	6	6	6	7	6	7	6
5	13	12	12	13	13	12	12	12	13	12	13	12	12	12	13
6	19	18	16	16	16	18	18	19	16	17	16	16	17	17	18
7	19	20	20	18	18	19	18	20	20	19	20	18	18	19	19
8	13	13	14	14	14	14	12	13	13	12	14	12	12	13	13
9	4	6	5	5	4	6	6	5	4	5	6	6	4	5	6
10	16	24	22	24	16	18	20	20	21	17	21	21	16	21	19
11	9	9	8	8	8	8	8	8	9	9	9	8	9	8	8
12	9	9	9	8	9	9	9	9	9	9	8	9	8	9	9
13	26	25	26	24	26	24	25	25	25	26	26	26	24	24	25
14	7	6	6	6	7	7	6	6	7	6	6	6	7	7	7
15	13	13	13	13	12	12	12	13	12	12	13	12	13	12	12
16	16	19	19	19	18	17	18	17	18	19	17	18	19	18	17
17	20	20	19	20	18	18	20	20	20	18	18	18	20	20	19
18	12	12	13	13	12	13	12	13	14	14	12	12	13	12	14
19	5	5	4	6	4	5	6	5	5	4	6	6	5	6	5
20	17	16	24	18	20	23	24	21	16	24	21	24	17	24	17
21	9	9	9	9	9	9	8	8	8	8	9	8	8	9	8
22	8	9	8	8	9	8	8	9	9	8	8	9	8	9	8
23	24	25	26	26	26	24	25	24	24	24	25	25	26	25	26
24	7	6	7	6	6	7	6	7	7	7	6	6	6	6	6
25	13	12	13	12	13	12	13	12	12	13	13	13	12	12	13
26	17	17	19	18	16	17	19	16	16	17	18	18	17	19	18
27	19	18	18	19	18	19	19	18	18	18	20	19	20	19	19
28	12	12	14	14	12	12	13	12	13	14	14	14	14	13	12
29	5	4	4	4	6	4	5	6	6	6	4	5	5	4	4
30	19	24	22	18	24	24	19	23	22	18	18	21	19	18	24
Capacity	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4

Table 15: AMS problem Example 2 flying hours and maintenance capacity slots from day 46 to 60.

Airplane\Day	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
1	9	9	9	9	8	9	8	9	9	9	8	9	9	8	8
2	9	9	9	8	8	8	8	9	8	9	8	8	9	9	8
3	25	25	24	26	25	24	24	25	25	26	24	24	24	24	26
4	6	7	7	6	6	7	6	7	7	6	6	6	7	6	6
5	12	13	13	13	12	12	12	13	13	13	13	12	12	12	12
6	18	17	16	16	18	18	16	19	19	16	16	16	17	18	18
7	18	20	18	18	18	19	19	18	20	19	20	19	18	19	18
8	12	12	14	14	13	12	13	12	12	13	14	14	14	13	13
9	6	6	6	5	6	5	5	6	6	6	5	5	5	6	6
10	21	22	20	24	23	23	23	16	17	21	18	19	20	16	19
11	9	8	9	8	9	8	8	9	9	9	9	9	8	9	8
12	9	8	8	9	9	9	8	9	9	9	8	8	8	9	9
13	26	26	26	26	26	24	25	26	26	26	25	26	25	25	25
14	7	7	7	6	7	6	6	6	7	6	6	7	6	6	6
15	13	13	12	12	13	12	13	13	12	13	13	12	13	13	12
16	19	17	18	16	16	17	19	19	19	18	18	16	18	16	18
17	18	18	20	19	18	20	19	18	20	18	19	20	18	20	20
18	14	13	14	12	14	13	12	14	12	13	12	14	14	14	13
19	4	5	6	6	6	5	5	5	5	4	6	4	4	6	6
20	24	17	21	22	17	16	16	17	16	19	20	16	16	18	16
21	8	8	8	9	9	8	8	8	8	8	8	9	9	9	9
22	8	9	9	8	8	8	8	9	9	9	9	8	8	8	8
23	24	25	24	25	25	25	26	24	25	26	25	26	25	25	24
24	7	7	6	6	6	7	7	6	7	6	7	7	6	7	7
25	12	12	13	13	12	12	12	13	12	12	12	13	12	13	13
26	16	19	16	18	19	16	17	19	19	16	18	19	16	16	17
27	20	20	18	18	18	20	20	19	19	19	18	18	19	18	20
28	13	12	14	12	13	14	12	14	12	12	13	14	13	14	13
29	6	6	6	4	4	5	5	6	4	6	6	5	6	6	6
30	17	22	23	17	16	23	19	19	19	16	22	16	22	18	20
Capacity	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4

Table 16: AMS problem Example 2 flying hours and maintenance capacity slots from day 61 to 75.

Airplane\Day	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75
1	9	8	8	9	8	8	8	9	8	9	9	8	9	9	9
2	8	8	9	8	9	9	8	8	9	9	9	8	9	9	9
3	26	26	25	26	26	26	26	24	26	25	26	24	24	25	26
4	6	6	6	6	7	6	6	7	7	6	6	6	6	6	7
5	13	12	12	12	13	13	12	12	13	13	13	13	12	12	13
6	18	18	16	18	16	18	17	18	16	16	18	17	16	19	19
7	18	19	19	19	20	19	20	19	20	19	19	18	20	20	18
8	12	13	12	14	13	12	13	12	13	13	12	13	13	12	12
9	6	6	4	6	6	4	5	5	6	6	4	4	6	4	4
10	17	24	16	20	22	20	19	19	19	19	16	18	23	20	16
11	9	9	8	9	9	8	9	9	9	9	9	8	8	8	8
12	9	8	9	9	9	8	9	9	8	8	9	8	8	8	9
13	25	24	24	25	25	26	24	25	26	25	25	25	26	25	24
14	7	6	6	6	7	7	6	7	7	6	6	7	6	6	6
15	12	13	12	13	12	13	12	12	13	12	13	12	13	13	12
16	18	19	16	18	17	17	16	19	16	16	18	17	18	18	17
17	20	20	19	19	20	19	18	20	18	18	19	20	18	19	18
18	14	12	12	13	12	12	14	13	12	12	12	14	13	14	14
19	5	4	5	4	4	4	5	5	5	5	6	4	6	5	5
20	21	22	17	22	18	20	23	16	21	24	24	16	16	24	22
21	8	9	8	9	9	9	8	9	9	8	9	9	8	8	8
22	8	8	9	8	8	9	8	8	9	8	8	9	8	9	8
23	24	24	25	26	26	24	25	25	26	25	26	24	25	26	24
24	6	6	6	6	6	6	7	7	6	6	7	6	6	6	6
25	13	13	12	12	13	12	12	12	13	13	12	12	13	13	13
26	19	19	19	18	19	16	17	18	17	19	18	18	16	18	18
27	19	19	19	19	18	18	19	18	19	19	20	18	20	18	18
28	14	13	12	13	12	12	14	13	12	12	12	14	13	13	13
29	5	6	5	5	5	5	5	6	4	6	5	5	4	5	6
30	19	20	16	23	19	23	23	19	24	21	16	20	18	23	21
Capacity	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4

Table 17: AMS problem Example 2 flying hours and maintenance capacity slots from day 76 to 90.

Airplane\Day	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
1	9	8	9	8	8	8	8	9	8	8	9	9	8	9	9
2	8	9	8	8	8	9	9	9	8	9	8	9	8	9	8
3	25	24	24	24	25	26	26	24	24	25	25	26	25	24	25
4	7	6	7	6	7	7	7	6	6	7	6	7	6	6	6
5	13	12	13	13	12	12	12	12	12	12	13	13	12	12	12
6	17	17	16	16	16	18	17	16	18	18	18	16	18	16	19
7	18	20	20	18	19	18	20	20	20	20	20	19	19	19	19
8	13	12	14	12	14	13	13	12	12	12	13	13	12	12	14
9	4	6	4	4	5	5	4	6	4	4	4	5	5	6	4
10	24	17	22	22	22	22	19	20	16	16	24	24	21	21	19
11	8	8	8	8	9	8	9	9	9	9	9	8	9	9	8
12	8	8	8	9	8	8	8	8	8	9	9	9	8	9	9
13	25	26	25	24	25	26	24	25	25	24	24	25	25	26	25
14	6	6	7	7	7	7	7	6	7	6	7	6	7	7	7
15	13	13	12	12	12	12	12	13	12	12	13	13	13	12	13
16	19	19	17	18	19	17	18	16	18	19	18	18	19	19	16
17	18	19	18	19	18	20	18	20	19	19	20	18	19	20	20
18	12	13	12	14	14	14	13	14	13	14	14	14	14	13	12
19	5	4	5	5	5	4	4	4	6	6	4	6	6	6	5
20	23	22	20	23	24	16	23	18	23	20	19	19	19	21	23
21	8	9	8	9	9	9	9	8	8	8	8	9	8	9	8
22	9	8	9	9	8	8	8	9	9	8	9	9	8	8	8
23	24	24	26	24	25	26	25	26	24	25	26	24	24	26	24
24	6	6	6	7	7	6	6	6	6	7	6	7	6	6	7
25	12	12	12	12	12	13	12	12	12	12	12	13	13	12	12
26	17	18	16	19	17	17	16	19	16	19	17	16	18	17	16
27	19	20	20	18	20	18	18	19	19	18	20	19	19	19	19
28	13	13	14	12	14	14	12	12	14	13	13	14	12	12	13
29	4	4	6	5	5	5	4	4	6	5	5	6	6	4	5
30	23	24	17	24	17	18	18	23	23	16	18	20	19	24	21
Capacity	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4

Table 0-18: AMS problem Example 2 flying hours and maintenance capacity slots from 91 to 105.

Airplane\Day	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105
1	8	8	9	8	8	8	9	9	8	8	8	9	8	9	8
2	8	9	8	9	9	9	8	8	8	8	8	9	8	9	8
3	25	24	25	24	24	26	26	25	24	25	25	25	25	26	25
4	7	7	7	6	6	6	6	6	7	6	6	6	6	7	6
5	12	13	12	12	13	12	12	13	12	12	13	13	12	12	12
6	17	16	19	19	17	16	17	17	17	19	18	17	19	17	17
7	19	18	19	19	18	18	20	19	20	18	19	19	20	19	19
8	13	12	14	13	14	14	14	13	13	13	13	13	14	13	12
9	5	4	4	4	6	5	6	6	4	6	4	6	4	4	4
10	22	24	16	20	16	19	19	18	17	19	18	23	16	22	18
11	9	9	8	8	8	8	8	8	9	8	9	9	9	9	9
12	8	8	9	9	8	9	9	9	8	9	9	8	9	9	9
13	24	24	26	24	24	26	24	24	24	25	24	26	24	25	26
14	6	7	6	7	7	7	6	6	6	6	6	7	7	7	6
15	12	12	12	12	12	12	12	13	13	12	12	13	12	13	13
16	16	19	19	16	19	18	19	17	16	19	18	19	18	16	17
17	19	18	18	20	20	18	19	19	18	19	20	18	19	20	18
18	12	12	12	14	12	14	14	12	12	14	12	12	14	13	13
19	6	4	6	6	5	5	6	4	4	5	5	4	6	4	4
20	24	19	16	19	17	22	20	20	17	22	21	22	22	19	19
21	8	8	9	8	8	9	9	8	9	8	9	9	8	9	8
22	8	9	9	9	9	8	9	9	8	9	8	8	8	8	9
23	26	26	26	25	26	26	26	26	25	26	24	26	24	25	26
24	6	6	6	6	7	7	7	6	6	7	7	7	7	6	6
25	13	13	13	13	12	12	12	13	12	12	13	12	12	12	12
26	17	17	19	17	17	18	18	19	17	16	16	18	19	16	16
27	20	19	19	18	18	18	19	20	18	20	19	20	18	18	18
28	13	13	14	14	14	14	14	13	14	13	14	13	13	14	12
29	4	6	6	4	4	5	4	4	6	5	5	5	5	5	4
30	24	16	19	16	17	23	22	22	19	23	20	22	20	16	23
Capacity	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4

Table 0-19: AMS problem Example 2 flying hours and maintenance capacity slots from 106 to 120.

Airplane\Day	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120
1	8	9	9	9	8	8	9	9	8	8	9	8	9	8	9
2	9	8	8	9	8	8	9	9	9	8	9	9	9	8	8
3	25	26	24	24	25	24	25	26	24	25	24	24	25	26	24
4	6	6	6	6	6	7	6	7	7	7	7	6	7	6	6
5	12	12	12	13	13	12	12	12	12	12	13	13	12	12	13
6	19	18	18	19	18	18	19	18	19	19	17	16	18	19	16
7	18	19	19	20	19	18	19	19	18	19	18	19	20	19	20
8	13	14	14	13	13	14	12	13	13	12	12	13	13	14	12
9	6	5	5	4	4	4	4	4	6	5	6	5	5	4	4
10	19	20	20	22	19	17	22	21	18	21	24	16	16	18	22
11	9	8	9	9	9	9	8	8	9	9	9	8	8	8	8
12	8	9	8	8	9	8	8	8	9	9	8	9	9	8	9
13	25	24	24	25	24	24	25	25	25	24	26	25	24	26	26
14	7	7	6	7	6	6	6	7	6	6	7	6	7	6	7
15	12	12	12	12	12	12	12	13	12	13	12	13	13	12	13
16	17	17	16	16	17	19	18	18	16	17	18	16	19	19	16
17	19	19	20	20	20	18	18	18	19	18	20	18	18	20	18
18	14	13	13	13	13	13	12	13	13	12	12	13	13	13	14
19	5	5	6	5	5	5	5	4	5	4	5	4	6	4	5
20	20	23	19	19	19	23	20	20	17	19	19	21	21	18	24
21	9	8	9	8	9	9	8	8	9	9	9	9	9	9	9
22	9	9	9	8	9	8	9	8	8	9	9	8	9	9	9
23	24	25	26	24	24	26	24	24	25	24	26	26	25	26	24
24	7	6	7	6	7	7	6	7	6	7	6	7	7	6	6
25	12	13	13	12	12	12	13	13	12	12	13	12	13	13	12
26	17	19	17	18	19	16	19	17	19	17	18	19	19	19	19
27	20	18	19	20	18	18	18	18	18	19	20	18	19	18	20
28	14	12	13	13	13	13	14	12	13	14	13	14	12	14	12
29	5	4	4	5	5	6	4	5	5	4	5	5	4	6	5
30	21	18	18	21	19	18	19	21	19	23	19	20	18	17	24
Capacity	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4

Table 20: Solution for AMS problem Example 2 from day 1 to 30.

airplane\Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1																					M1									
2																														
3										M1																				
4																														
5																													M1	M1
6				M1																										
7			M1																											
8																												M1		
9																														
10																													M1	
11																														
12								M1																						
13															M1															
14														M1																
15								M1	M1																					
16			M1																											
17																														
18																					M1									
19																									M1					
20																	M1													
21																									M1					
22																														
23								M1																						
24			M1																											
25				M1																										
26																		M1												
27	M1																													
28																											M1			
29																													M1	
30																														

Table 21: Solution for AMS problem Example 2 from day 31 to 60.

airplane\Day	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
1																														
2				M1																										
3																			M2											
4	M1																													
5																														
6																		M2												
7				M2																										
8																														
9																						M1								
10																														
11							M1																							
12																						M2								
13																									M2	M2				
14																										M2				
15																										M2				
16															M2															
17							M1																							
18																														
19																														
20																							M2							
21																														
22													M1																	
23																	M2	M2												
24															M2															
25				M2																										
26																														
27										M2																				
28																										M2				
29																														
30						M1																								

Table 22: Solution for AMS problem Example 2 from day 61 to 90.

airplane\Day	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
1				M2																										
2																		M2												
3																												M3		
4														M2																
5																	M2													
6																														
7					M3																									
8														M2																
9																													M2	M2
10						M2																								
11																						M2								
12																														
13																														
14																														
15																														
16																										M3				
17																M2														
18								M2	M2																					
19																			M2											
20																														M3
21									M2																					
22																										M2				
23																											M3			
24																												M3		
25				M3																										
26	M2																													
27																			M3											
28																								M3						
29																						M2								
30													M2																	

Table 23: Solution for AMS problem Example 2 from day 91 to 120.

airplane\Day	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120
1																		M3												
2																														
3																														
4																										M3				
5																														
6	M3																													
7																														M4
8																														M3
9																														
10														M3	M3															
11																														
12						M3																								
13					M3																									
14								M3																						
15														M3																
16																														
17																									M3					
18																								M3						
19																														
20																														
21																							M3							
22																														
23																														
24																														
25																													M4	
26													M3																	
27																													M4	M4
28																														M4
29																														
30																				M3										

Example 3

Table 24: AMS Example 3 maintenance checks and maintenance interval data.

Airplane	LT	UT	ST	M1	M2	M3	M4
1	300	375	247	1	1	1	2
2	300	375	211	1	1	1	-
3	700	1000	92	1	1	1	-
4	150	275	248	1	2	1	1
5	400	600	435	1	1	1	-
6	600	750	387	1	1	1	1
7	400	600	259	1	1	1	1
8	400	600	528	1	1	1	1
9	150	275	49	1	1	0	-
10	600	750	579	1	1	1	1
11	300	375	262	1	1	1	1
12	300	375	167	1	1	1	-
13	700	1000	86	1	1	1	-
14	150	275	61	1	1	1	-
15	400	600	288	1	2	1	-
16	600	750	129	1	1	1	-
17	600	750	65	2	1	1	-
18	400	600	246	1	1	2	-
19	150	275	37	2	1	-	-
20	600	750	187	1	1	1	2
21	300	375	16	1	1	1	-
22	300	375	15	1	1	1	-
23	700	1000	399	2	1	1	1
24	150	275	128	1	2	1	1
25	300	375	174	1	1	1	2
26	600	750	254	1	1	1	-
27	600	750	406	1	1	1	1
28	300	375	31	1	1	1	1
29	150	275	73	1	1	1	-
30	600	750	151	1	1	1	1
31	300	375	166	1	1	1	-
32	300	375	102	1	1	1	-
33	700	1000	330	1	1	1	1
34	150	275	208	1	1	1	1
35	400	600	307	1	1	1	-
36	600	750	224	1	1	1	-
37	400	600	451	1	1	2	1
38	400	600	350	1	1	1	-
39	150	275	247	1	1	1	-
40	600	750	94	1	2	1	1

Table 25: AMS problem Example 3 flying hours and maintenance capacity slots from day 1 to 15.

Airplane\Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	8	8	8	8	8	9	9	8	8	9	8	8	8	8	8
2	8	8	9	9	8	9	9	8	9	8	9	8	8	9	8
3	24	25	25	24	24	25	24	25	25	25	24	26	25	25	26
4	7	6	6	7	6	6	6	6	6	7	7	6	7	6	6
5	13	13	13	12	13	12	12	13	13	13	13	12	13	12	12
6	19	19	19	16	18	19	16	18	19	18	19	17	16	19	16
7	18	19	20	18	19	20	20	19	19	20	18	18	19	18	18
8	13	14	13	14	13	14	14	14	14	12	13	13	12	13	12
9	5	5	4	6	5	6	6	5	4	5	6	5	6	6	4
10	20	16	20	16	23	19	16	18	21	24	16	22	18	18	23
11	8	9	8	8	9	8	9	8	8	9	9	9	9	9	9
12	8	8	8	8	8	8	9	9	8	8	8	9	8	8	9
13	26	24	24	24	24	26	25	25	26	24	24	25	26	26	26
14	7	6	6	6	6	6	6	6	7	7	6	6	7	7	6
15	12	12	13	13	13	12	12	12	13	12	13	13	13	13	13
16	17	19	17	16	16	18	19	18	17	16	19	17	18	18	18
17	18	18	18	19	19	18	18	18	19	18	20	20	19	20	19
18	12	13	13	14	12	14	12	12	13	13	12	12	14	14	13
19	5	6	4	4	4	5	4	4	6	5	6	6	5	6	6
20	21	17	16	17	19	17	24	21	21	19	19	23	22	21	16
21	8	9	9	9	8	9	9	9	8	9	9	9	9	8	9
22	8	9	8	9	9	8	8	9	9	9	9	8	9	8	8
23	24	26	24	25	24	24	26	26	24	24	25	24	26	26	26
24	6	7	6	7	6	6	6	7	6	7	6	7	7	7	7
25	13	12	13	13	13	12	12	13	12	12	12	13	12	13	13
26	17	18	17	17	18	17	18	17	16	19	17	17	16	19	19
27	18	20	18	20	18	19	18	18	18	20	18	20	18	20	18
28	14	12	12	12	14	14	12	12	12	13	12	14	12	12	12
29	6	6	6	5	5	5	5	4	4	6	4	5	5	4	4
30	20	17	22	23	19	17	19	16	24	19	20	21	16	16	19
31	8	9	9	9	9	8	9	9	9	9	9	8	9	8	9
32	9	8	9	9	8	8	8	9	9	8	8	9	9	9	9
33	25	24	26	26	26	26	26	25	24	26	26	24	25	26	25
34	7	6	6	6	6	6	7	7	7	7	6	6	7	6	7
35	12	12	13	12	12	12	13	12	12	13	13	12	12	13	13
36	18	16	16	19	18	18	19	17	17	18	17	17	16	16	16
37	20	19	19	19	20	18	20	18	20	19	20	19	19	20	19
38	13	12	13	12	12	13	14	13	13	13	13	14	13	12	14
39	6	4	4	5	6	4	5	4	6	4	6	4	6	5	6
40	18	22	18	18	23	24	23	22	24	20	22	18	17	23	22
Capacity	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3

Table 26: AMS problem Example 3 flying hours and maintenance capacity slots from day 16 to 30.

Airplane\Day	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	9	8	8	9	8	8	8	9	9	9	8	9	9	9	8
2	8	8	9	8	9	8	9	8	8	8	9	8	9	9	9
3	26	24	26	25	25	24	24	24	25	26	25	26	26	24	24
4	7	7	7	6	7	6	6	7	7	7	6	7	7	7	6
5	13	13	12	12	13	12	12	13	13	13	13	12	13	13	13
6	18	16	18	17	19	17	19	17	16	18	19	17	19	19	17
7	20	19	19	19	20	19	18	20	18	18	18	20	18	18	19
8	13	14	13	12	12	13	14	12	12	13	12	12	12	13	13
9	4	4	5	5	4	6	6	5	5	6	6	5	6	6	6
10	17	24	24	23	20	24	18	16	17	21	16	23	24	22	18
11	9	9	9	8	8	8	8	8	9	9	8	8	8	9	9
12	8	8	9	8	9	8	9	8	9	8	8	9	8	8	9
13	24	25	25	24	24	24	25	26	26	24	24	24	25	24	25
14	6	7	6	7	7	7	6	7	7	6	7	7	7	7	6
15	13	12	13	13	12	12	13	12	13	12	12	12	13	13	13
16	18	19	18	19	18	18	19	18	18	19	16	17	16	17	18
17	20	18	18	18	18	18	19	19	18	18	20	19	19	20	20
18	12	14	12	13	13	12	12	12	12	12	14	13	14	12	14
19	4	4	5	4	6	5	4	4	6	6	5	6	4	5	5
20	21	24	20	19	19	20	22	16	17	24	19	18	18	18	20
21	9	9	8	9	8	8	9	9	9	8	8	9	9	9	9
22	9	8	8	9	9	9	8	9	9	8	9	8	8	9	8
23	26	25	25	26	24	24	24	24	24	25	24	24	24	25	25
24	7	6	7	7	7	7	6	6	6	7	7	7	6	6	6
25	12	13	13	12	12	13	13	13	12	13	13	13	13	12	12
26	17	17	18	17	19	17	19	17	19	17	16	18	19	16	19
27	19	20	19	18	19	20	18	18	19	18	20	18	20	20	18
28	13	12	14	12	13	14	13	12	14	12	13	13	14	13	12
29	4	6	4	6	6	6	6	5	4	5	4	6	5	4	5
30	23	18	24	17	24	23	16	19	22	19	17	17	21	24	20
31	9	8	8	8	9	8	9	9	9	9	8	8	9	9	9
32	9	9	9	9	9	8	9	8	8	8	8	9	8	8	9
33	25	24	24	26	26	24	26	25	25	24	26	25	24	24	24
34	7	7	7	7	7	6	6	6	7	7	7	7	6	6	7
35	13	13	12	13	13	13	12	13	13	12	13	13	13	13	12
36	16	19	18	18	16	19	16	18	17	17	17	18	17	16	18
37	19	20	18	18	18	20	18	19	20	18	20	19	19	19	18
38	13	12	12	14	13	14	12	14	13	14	13	13	13	13	14
39	4	6	6	6	4	5	4	4	4	6	5	4	5	5	4
40	16	16	17	18	21	21	21	17	22	21	24	20	16	23	17
Capacity	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3

Table 27: AMS problem Example 3 flying hours and maintenance capacity slots from day 31 to 45.

Airplane\Day	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
1	9	8	9	8	8	9	9	8	8	9	9	8	9	9	8
2	9	9	9	8	8	9	8	9	8	8	9	8	8	8	8
3	24	25	26	26	25	24	25	26	25	26	26	26	24	26	25
4	6	6	6	7	7	6	7	7	7	6	7	7	6	6	6
5	13	12	13	12	12	13	12	12	12	13	12	12	12	12	13
6	18	18	18	19	19	18	17	18	18	19	18	17	17	19	18
7	18	20	20	18	20	20	20	19	20	20	18	19	18	18	18
8	12	13	13	14	14	13	12	13	12	12	12	14	13	14	14
9	5	6	6	4	6	5	4	5	4	5	4	6	4	6	6
10	16	22	21	21	21	18	22	18	22	20	19	24	21	21	18
11	8	8	8	8	9	9	8	9	9	8	9	8	8	8	9
12	8	9	9	9	9	8	8	8	8	8	9	8	8	8	9
13	24	26	25	25	24	26	26	25	26	26	25	24	26	24	26
14	7	7	6	6	6	6	7	7	6	7	6	7	6	7	7
15	13	12	12	13	12	12	13	13	12	12	13	13	12	12	13
16	19	17	18	16	19	19	19	17	17	19	19	17	17	19	17
17	19	20	20	18	20	18	20	20	19	18	19	20	19	19	19
18	13	14	12	14	13	13	14	13	14	14	13	12	14	14	12
19	4	4	4	5	6	5	4	4	6	5	5	5	4	4	5
20	16	16	16	17	22	22	21	17	20	21	18	18	24	21	18
21	8	8	9	8	9	8	8	9	9	8	9	8	9	8	8
22	9	8	8	8	8	9	9	9	8	8	8	8	8	8	8
23	24	25	26	24	24	26	26	26	24	26	26	24	24	25	26
24	7	7	7	7	6	7	6	6	6	7	7	6	7	6	7
25	13	13	13	12	12	12	12	12	13	12	13	12	13	12	12
26	18	18	16	17	16	18	17	18	18	19	17	16	17	17	18
27	20	18	20	18	20	20	19	19	18	18	18	19	20	19	20
28	12	12	14	12	13	14	12	12	14	13	13	12	14	12	13
29	5	6	4	5	4	4	4	5	5	4	6	6	6	5	5
30	16	18	20	21	21	20	16	24	16	23	19	16	17	23	17
31	8	9	8	9	8	9	9	8	8	9	9	9	9	9	9
32	9	9	8	9	8	8	9	9	9	8	9	9	8	9	8
33	26	25	24	24	24	26	24	25	26	24	24	26	26	24	26
34	6	6	6	6	6	6	7	7	7	6	7	6	7	6	7
35	12	12	12	12	13	13	12	12	12	12	13	13	13	13	12
36	19	18	17	18	17	18	19	17	17	16	19	16	18	17	18
37	20	19	19	20	19	20	18	19	18	18	19	18	18	19	20
38	13	12	13	14	14	14	14	12	13	13	14	14	12	14	14
39	5	5	6	5	5	4	5	4	4	6	4	5	6	6	4
40	24	17	20	21	20	21	22	18	18	19	21	22	24	18	16
Capacity	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3

Table 28: AMS problem Example 3 flying hours and maintenance capacity slots from day 46 to 60.

Airplane\Day	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
1	9	8	8	8	9	8	8	9	9	8	8	8	9	9	9
2	9	9	9	9	9	9	8	9	8	8	8	8	8	9	8
3	26	25	26	24	25	26	25	26	24	25	25	25	26	24	24
4	6	7	7	6	6	6	6	7	6	6	6	6	7	6	7
5	12	13	13	12	13	13	12	13	13	13	12	13	12	13	12
6	19	19	19	16	16	18	19	17	19	18	17	18	18	16	17
7	19	20	18	19	18	19	20	19	18	18	18	18	20	18	19
8	14	13	14	13	14	12	12	14	12	12	12	13	13	12	12
9	4	6	6	6	4	6	6	5	6	4	4	6	4	5	4
10	17	21	22	19	20	23	18	22	23	22	18	24	17	20	18
11	8	8	9	9	9	9	9	8	8	9	8	9	9	8	9
12	8	8	8	8	9	8	9	8	9	8	9	8	9	9	9
13	24	25	26	24	24	25	24	26	26	24	24	26	25	24	26
14	6	6	6	6	6	7	7	6	6	7	7	7	6	7	7
15	13	13	13	13	12	13	13	12	12	12	12	13	12	13	13
16	16	19	17	19	19	16	19	16	17	18	18	16	18	17	18
17	18	18	19	19	19	19	18	18	19	20	18	18	18	18	20
18	12	14	12	13	13	12	13	13	14	13	13	14	12	13	12
19	6	5	6	5	6	4	5	6	6	4	4	4	5	6	4
20	20	19	18	16	17	20	18	19	23	18	21	23	19	23	24
21	9	8	8	8	8	8	8	8	8	8	9	9	9	8	9
22	8	8	9	8	8	9	8	8	9	9	8	9	9	9	9
23	25	24	24	26	24	24	25	25	26	24	26	24	25	25	24
24	7	6	6	6	7	6	7	6	6	6	7	6	7	7	7
25	12	12	12	13	12	13	13	12	12	12	12	12	13	13	12
26	17	19	17	18	16	17	16	18	16	17	17	19	17	19	17
27	18	18	20	18	18	18	19	20	19	19	19	19	18	20	18
28	14	12	12	13	14	14	13	13	14	14	13	12	12	13	13
29	5	5	5	6	6	4	6	6	5	6	6	6	5	4	6
30	16	24	21	19	17	23	16	19	20	16	23	24	16	16	21
31	9	8	8	9	9	8	9	8	8	9	8	9	9	8	8
32	8	8	9	9	8	9	8	9	8	8	9	9	8	9	8
33	25	25	24	25	24	25	26	24	25	24	26	24	24	24	24
34	6	6	7	7	6	7	7	6	6	7	6	7	6	7	6
35	12	13	13	12	13	12	12	12	13	13	12	12	12	12	13
36	16	19	18	18	18	17	19	16	19	18	17	17	16	18	19
37	20	20	18	20	20	19	18	19	19	18	19	19	20	20	18
38	12	13	12	12	14	14	14	12	12	14	13	12	14	13	14
39	6	5	4	5	6	4	5	4	5	6	4	5	6	5	5
40	23	20	18	21	17	24	22	24	21	17	21	18	20	19	16
Capacity	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3

Table 29: AMS problem Example 3 flying hours and maintenance capacity slots from day 61 to 75.

Airplane\Day	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75
1	9	8	9	9	8	9	8	8	8	8	9	8	8	9	8
2	9	8	9	8	8	9	9	8	9	9	9	9	9	9	9
3	24	25	25	26	25	26	24	24	25	26	26	25	25	26	26
4	7	7	7	6	6	6	6	6	7	6	6	6	6	6	6
5	13	12	12	13	12	12	13	12	12	12	13	13	13	12	13
6	19	16	16	17	17	17	17	17	18	18	18	18	18	19	19
7	20	18	20	18	20	20	19	19	19	20	19	18	19	20	20
8	12	13	12	14	13	14	12	13	13	14	13	13	12	13	13
9	4	6	5	5	4	4	5	4	5	5	6	4	5	4	4
10	24	19	22	22	23	24	16	19	19	20	22	19	18	23	24
11	9	8	8	9	9	8	9	8	8	9	9	8	9	9	9
12	8	9	9	8	8	9	9	8	8	9	8	9	9	8	9
13	25	24	25	26	25	24	26	24	24	26	25	25	26	26	26
14	7	7	6	6	7	6	7	7	7	7	7	6	7	6	6
15	12	12	13	12	12	12	13	12	13	12	12	12	12	12	13
16	16	17	18	18	17	17	19	17	18	19	17	18	18	18	16
17	18	19	19	20	20	19	18	18	20	20	18	19	18	18	18
18	12	13	12	12	14	12	12	13	13	13	14	13	12	13	14
19	5	5	5	5	5	5	4	4	4	5	4	4	6	5	6
20	16	22	18	18	23	24	17	20	24	22	23	24	20	18	20
21	8	8	8	8	9	8	8	8	8	9	8	8	8	9	8
22	8	9	9	8	8	8	9	8	8	8	8	8	9	9	9
23	26	25	26	26	24	24	25	25	24	26	24	25	25	26	24
24	7	6	6	7	7	6	6	6	7	6	6	6	6	7	6
25	13	13	13	12	12	12	13	13	12	13	13	13	12	13	13
26	19	18	17	18	19	18	18	17	18	19	19	19	16	16	19
27	20	20	18	19	18	19	19	19	19	19	19	19	20	18	20
28	13	14	14	12	13	13	14	12	14	12	12	13	13	14	14
29	5	4	5	4	4	4	6	6	4	6	4	4	6	4	5
30	23	21	21	23	16	20	23	17	20	16	22	22	17	24	19
31	8	9	8	9	8	8	9	9	8	9	9	9	8	9	8
32	9	8	8	8	9	8	8	8	9	9	8	9	9	8	9
33	26	25	24	24	26	26	26	24	25	26	25	25	26	25	25
34	7	7	6	6	6	6	7	7	6	7	7	6	7	6	7
35	12	12	12	13	13	13	12	13	13	13	12	12	12	12	13
36	16	18	16	18	18	16	17	18	17	19	17	19	18	17	18
37	19	18	18	18	19	19	20	18	18	20	20	19	20	19	20
38	12	13	12	13	13	12	14	14	13	14	14	13	14	12	14
39	4	5	4	4	4	6	6	5	4	4	6	5	5	5	6
40	24	22	17	20	20	21	17	23	16	22	24	21	17	18	21
Capacity	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3

Table 30: AMS problem Example 3 flying hours and maintenance capacity slots from day 76 to 90.

Airplane\Day	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
1	8	9	8	9	8	8	9	8	9	9	8	8	9	9	9
2	8	8	9	9	9	9	8	8	8	9	9	8	9	9	9
3	26	26	25	26	25	25	24	26	26	26	25	26	25	26	26
4	7	7	6	7	6	6	7	6	6	6	7	7	6	7	7
5	13	13	12	12	12	12	13	12	12	13	13	12	12	12	13
6	16	16	18	18	16	19	16	19	18	19	19	17	19	18	19
7	20	18	19	20	18	18	20	19	19	20	18	20	19	20	18
8	14	14	12	14	13	14	12	12	14	12	12	13	12	13	13
9	5	4	6	5	6	5	6	6	6	6	6	5	5	4	4
10	18	24	17	21	17	19	16	23	24	19	19	23	20	16	21
11	9	9	8	9	9	8	8	9	8	9	8	9	8	8	9
12	8	9	9	9	9	8	8	8	8	8	8	9	8	8	8
13	26	24	24	24	26	26	26	26	25	24	26	26	25	24	25
14	7	7	6	6	6	7	6	6	7	6	7	7	7	7	7
15	12	13	12	12	13	12	12	12	12	13	12	12	13	13	12
16	19	19	19	19	19	19	16	17	19	16	17	18	16	16	18
17	18	20	18	20	18	19	18	20	18	20	18	18	20	19	20
18	14	13	14	13	13	13	13	12	14	12	13	14	14	13	14
19	5	6	6	6	5	6	6	5	4	4	6	4	6	4	6
20	19	22	24	21	19	17	22	16	22	19	19	24	22	16	17
21	8	8	8	8	9	8	8	8	8	9	9	8	9	8	8
22	8	8	8	8	8	8	9	9	9	8	8	8	8	8	8
23	25	25	26	25	25	24	24	26	24	26	24	24	25	25	24
24	7	6	7	6	6	7	6	7	7	7	7	6	6	7	6
25	13	13	12	13	13	12	12	12	12	12	13	13	12	13	13
26	16	18	16	18	16	18	16	18	17	16	19	19	18	17	19
27	18	18	19	18	20	19	19	19	19	20	20	19	20	19	19
28	13	12	14	13	12	14	14	13	14	13	12	14	12	13	13
29	5	5	6	5	6	4	5	5	5	6	6	4	6	6	4
30	18	20	19	23	21	20	19	19	16	22	21	21	17	19	22
31	9	9	9	8	9	8	9	9	8	8	8	8	9	8	9
32	8	9	8	9	8	8	8	8	9	9	9	8	8	9	8
33	24	25	26	26	25	24	26	25	25	24	24	26	26	24	26
34	7	6	7	6	7	6	6	6	6	7	6	7	7	7	7
35	13	13	12	13	13	12	12	13	12	13	12	12	13	12	12
36	18	16	18	19	17	19	17	19	16	16	19	19	17	18	19
37	18	19	19	20	20	18	19	19	20	20	20	20	20	20	18
38	14	12	14	13	13	13	14	13	12	14	14	13	13	12	13
39	6	5	5	6	6	6	4	5	4	5	6	6	4	5	6
40	17	21	20	17	21	23	17	23	21	18	17	18	20	24	21
Capacity	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3

Table 31: AMS problem Example 3 flying hours and maintenance capacity slots from day 91 to 105.

Airplane\Day	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105
1	9	9	8	9	9	9	9	8	8	8	9	9	9	8	9
2	9	9	9	8	8	9	9	9	8	9	9	9	9	8	9
3	26	26	26	26	24	24	24	25	26	24	25	26	24	25	26
4	7	6	6	6	7	7	6	7	7	7	6	7	6	7	7
5	12	13	12	13	12	13	12	12	12	12	12	12	13	13	13
6	16	16	17	18	18	16	16	18	18	16	17	18	17	17	17
7	19	19	20	18	20	20	20	20	19	19	19	20	19	18	18
8	14	13	13	14	12	13	13	12	13	14	12	13	12	13	12
9	6	5	6	5	4	4	4	4	6	6	6	4	5	4	4
10	19	22	22	17	24	17	19	24	20	22	24	17	21	24	17
11	8	9	8	9	8	8	9	9	8	9	8	8	9	9	8
12	8	9	8	9	9	9	8	9	9	8	9	8	8	9	8
13	25	24	26	26	24	26	26	24	25	24	26	26	25	26	26
14	6	7	7	6	7	6	7	6	6	6	6	6	6	6	6
15	12	13	13	13	12	12	13	12	13	12	12	12	13	12	12
16	19	19	17	16	18	16	19	19	19	19	18	16	16	19	16
17	18	19	20	18	19	19	18	20	18	19	19	20	20	20	20
18	12	12	13	12	12	12	12	14	12	12	13	13	14	14	12
19	6	6	4	6	6	6	5	6	5	6	5	4	6	4	5
20	18	19	16	19	21	22	20	19	19	22	23	23	23	24	20
21	9	9	8	9	9	9	9	9	8	8	8	9	9	8	9
22	9	9	9	8	9	9	8	9	8	9	8	8	9	8	9
23	25	25	24	25	26	24	25	25	25	25	25	26	25	26	25
24	7	7	7	7	7	6	6	6	7	7	7	6	6	6	6
25	12	12	12	13	13	12	12	12	13	13	13	12	13	12	13
26	17	19	16	18	16	18	18	17	17	18	16	16	18	19	16
27	18	19	20	19	19	20	18	18	18	18	19	18	20	18	19
28	12	14	12	12	12	13	12	13	13	14	13	12	13	14	12
29	5	6	6	6	5	4	6	5	4	6	5	6	6	4	6
30	23	23	19	22	23	16	19	20	19	17	21	17	24	23	16
31	8	9	9	8	8	9	9	9	8	9	9	8	8	9	8
32	8	9	8	9	8	8	9	8	9	9	9	9	9	9	9
33	24	24	25	25	25	26	26	24	25	26	24	25	24	26	25
34	7	6	6	6	6	7	7	7	6	6	7	6	6	7	7
35	13	12	13	12	12	12	13	13	12	12	13	12	12	13	13
36	18	19	18	18	18	16	17	17	17	16	16	19	18	18	17
37	18	20	19	20	19	18	18	18	18	19	18	19	18	20	19
38	14	13	12	13	12	13	13	14	12	14	13	12	12	14	13
39	6	6	5	5	4	5	5	4	4	4	6	6	4	6	5
40	17	22	23	22	24	24	18	17	21	23	21	20	19	20	21
Capacity	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3

Table 32: AMS problem Example 3 flying hours and maintenance capacity slots from day 106 to 120.

Airplane\Day	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120
1	8	8	8	9	8	9	8	9	9	9	8	9	9	8	9
2	8	9	8	9	8	9	8	8	9	9	8	8	8	8	8
3	25	24	24	24	26	25	24	24	25	24	25	24	24	24	24
4	7	7	6	7	7	7	6	7	6	7	6	6	6	6	7
5	12	12	13	12	12	13	13	12	13	13	12	13	12	12	13
6	19	18	16	17	19	18	19	16	18	17	19	19	16	16	16
7	20	18	19	20	18	19	20	19	19	19	18	18	19	19	19
8	14	13	14	13	12	14	12	12	14	13	13	14	12	12	13
9	5	4	5	6	4	6	4	5	4	6	4	6	6	6	5
10	20	22	18	22	17	20	23	21	17	18	17	24	16	17	17
11	9	9	9	9	8	8	8	8	9	8	9	8	9	9	9
12	9	8	9	8	8	9	8	8	9	8	8	9	8	9	9
13	26	25	25	26	25	25	26	25	25	24	24	25	25	26	24
14	7	7	6	6	6	6	6	6	6	7	7	6	7	6	6
15	13	13	13	12	13	13	12	13	13	12	13	12	13	12	12
16	19	18	19	18	19	17	17	16	16	18	16	19	17	18	18
17	19	20	19	18	20	19	18	18	18	20	18	20	20	18	18
18	14	14	13	14	13	14	13	12	13	12	13	12	12	14	12
19	4	5	5	6	5	5	6	5	4	5	4	6	5	6	4
20	24	17	22	19	21	24	21	19	17	23	18	18	16	18	19
21	9	8	9	9	8	9	8	8	9	8	9	8	9	8	9
22	9	8	9	8	9	9	9	8	8	8	9	9	8	9	9
23	24	25	26	25	24	26	24	24	25	25	26	24	25	24	25
24	7	6	6	7	7	6	7	6	6	7	6	6	7	6	6
25	12	13	13	12	12	13	13	12	13	13	12	12	13	13	12
26	18	19	19	18	17	16	18	16	19	17	18	16	19	16	19
27	19	19	20	19	19	20	19	18	20	19	20	19	20	19	19
28	13	12	14	14	12	13	14	12	13	14	13	14	14	14	13
29	6	4	4	4	6	6	5	4	5	6	5	5	6	5	5
30	23	21	22	16	19	20	21	17	20	20	20	17	18	23	18
31	9	9	9	9	9	8	8	9	9	9	9	9	8	9	8
32	9	9	9	9	9	8	9	9	8	8	8	9	9	9	9
33	24	25	26	24	25	24	26	26	25	24	25	26	26	26	24
34	6	7	6	6	7	7	6	7	7	6	6	7	7	6	6
35	13	13	12	13	12	13	13	13	12	12	13	12	13	13	13
36	19	18	16	17	16	17	16	18	17	19	19	16	18	18	19
37	19	18	20	18	18	18	20	18	18	19	20	18	20	20	19
38	13	14	14	14	13	14	12	13	13	13	12	12	12	13	12
39	4	5	4	6	4	6	6	6	6	5	5	5	6	4	4
40	21	21	19	18	22	18	16	21	22	17	17	23	22	16	19
Capacity	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3

Table 33: AMS problem Example 3 flying hours and maintenance capacity slots from day 121 to 135.

Airplane\Day	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135
1	9	9	9	9	9	9	8	8	9	8	8	9	9	9	8
2	9	8	9	8	9	9	9	9	8	9	9	9	8	8	8
3	25	24	25	24	26	24	25	26	26	24	26	26	24	24	24
4	6	6	7	6	6	6	7	6	7	6	7	7	6	6	6
5	12	12	12	13	13	12	12	13	12	12	12	12	13	12	12
6	19	16	18	17	16	18	16	16	16	18	17	18	18	16	17
7	19	19	20	19	18	18	18	20	20	19	20	19	19	18	19
8	13	14	13	13	14	14	13	12	14	12	14	12	13	12	12
9	6	5	6	6	5	4	5	6	6	4	6	4	5	6	5
10	22	22	22	18	21	23	17	22	20	24	16	22	17	23	20
11	8	8	8	9	9	8	9	9	9	8	8	9	9	8	9
12	8	8	8	9	9	8	8	9	8	9	9	9	9	8	8
13	24	24	24	26	25	26	25	25	25	25	25	24	26	26	24
14	6	7	7	6	6	7	6	6	6	6	7	6	6	7	7
15	13	12	13	12	12	13	12	13	13	12	12	12	13	12	13
16	19	18	18	18	18	17	17	18	16	16	18	16	18	19	16
17	19	20	19	19	19	19	18	18	19	19	20	20	19	19	19
18	14	14	12	12	13	14	14	14	14	13	13	12	12	14	13
19	4	4	5	4	5	5	4	6	4	6	5	5	5	4	6
20	24	17	17	23	21	19	24	24	21	18	23	17	22	18	21
21	8	9	8	8	8	8	9	8	8	9	9	9	9	9	9
22	8	8	8	8	8	8	9	8	9	9	8	9	9	9	8
23	26	26	24	24	25	24	24	26	25	24	24	25	26	24	24
24	7	6	6	7	6	6	7	7	6	7	7	6	6	6	7
25	12	13	12	12	12	13	12	13	12	13	13	13	12	12	12
26	19	16	17	17	16	17	17	18	17	17	18	18	18	18	18
27	20	20	19	19	20	19	20	20	20	18	18	20	20	19	20
28	14	12	13	12	13	14	12	12	13	13	12	13	13	14	14
29	6	4	4	4	4	4	5	4	6	5	4	5	4	5	6
30	23	23	18	21	20	23	19	21	24	23	22	16	18	24	20
31	8	9	9	9	9	8	8	8	9	9	8	9	8	9	9
32	9	8	8	8	9	9	8	8	8	8	9	8	9	9	9
33	25	24	24	26	26	25	24	24	26	26	26	26	25	26	26
34	7	7	6	6	7	6	6	6	7	6	7	6	7	7	7
35	13	13	12	12	13	12	12	12	13	13	13	13	12	13	12
36	18	18	16	17	17	17	18	16	16	17	16	19	18	17	17
37	19	18	18	18	18	19	19	19	18	20	19	20	20	19	19
38	12	14	14	12	12	14	12	12	13	12	12	13	12	12	12
39	5	4	6	5	5	4	6	6	6	5	4	5	6	4	4
40	18	20	23	17	24	21	20	16	19	23	19	16	17	18	24
Capacity	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3

Table 34: AMS problem Example 3 flying hours and maintenance capacity slots from day 136 to 150.

Airplane\Day	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150
1	9	9	8	8	9	8	8	9	8	9	8	8	9	8	9
2	8	8	8	9	9	8	8	9	8	8	9	9	9	8	8
3	24	25	24	25	26	26	25	25	25	26	25	26	26	24	24
4	6	6	7	6	6	6	7	7	6	7	7	7	7	6	6
5	12	12	12	13	13	13	12	13	12	13	13	13	12	13	12
6	18	19	19	16	17	18	17	16	16	17	19	17	19	16	17
7	20	19	19	19	18	19	19	20	18	20	18	20	20	20	18
8	13	13	13	14	12	13	12	14	12	14	13	14	12	14	12
9	5	4	5	4	6	6	6	6	4	4	6	6	6	5	5
10	24	23	23	16	17	21	22	24	21	24	23	24	20	17	24
11	8	8	9	8	8	8	8	8	8	8	9	9	9	9	9
12	8	9	9	8	8	9	8	8	8	9	8	9	9	8	9
13	24	26	26	24	25	24	26	25	24	24	26	26	25	26	25
14	7	7	7	6	6	6	7	7	6	6	7	6	7	7	7
15	12	12	12	12	12	13	13	12	12	13	12	12	13	12	13
16	18	16	16	19	16	19	19	16	17	18	18	19	19	19	19
17	18	18	18	19	20	18	20	19	18	20	20	18	20	18	20
18	12	13	13	13	12	12	14	12	14	12	14	12	13	12	14
19	6	5	5	6	4	6	6	6	4	5	5	4	6	6	6
20	24	19	16	17	16	17	23	17	18	16	23	19	19	16	24
21	8	9	8	9	8	8	9	8	9	8	9	9	9	8	8
22	8	8	8	8	8	9	8	8	9	9	8	9	9	9	8
23	26	26	24	24	26	25	26	24	24	25	26	24	26	26	26
24	6	7	7	7	7	6	6	6	7	6	6	7	6	6	6
25	13	13	13	12	13	13	12	12	13	13	12	12	13	13	12
26	16	18	17	19	18	19	19	18	19	19	17	18	16	17	19
27	20	20	19	20	19	18	20	20	19	20	18	20	19	20	18
28	14	14	12	14	14	12	13	14	13	12	14	12	13	12	12
29	6	6	6	5	6	5	6	5	6	5	4	5	5	4	4
30	21	20	23	24	16	21	19	22	23	23	16	17	23	16	22
31	8	8	8	8	8	9	9	9	8	8	9	9	8	8	8
32	8	8	8	9	8	9	9	8	8	8	8	9	9	8	8
33	25	25	25	24	25	24	26	24	26	26	25	25	24	26	25
34	6	7	6	6	7	6	7	6	6	6	7	6	6	7	7
35	13	13	13	13	12	13	12	12	12	12	12	12	12	13	12
36	17	16	17	17	18	18	19	18	18	19	17	19	17	18	17
37	18	20	19	19	19	20	19	20	18	20	18	18	18	20	20
38	14	12	14	12	14	14	14	12	13	13	14	13	14	14	13
39	6	5	4	4	4	4	6	6	4	4	6	6	6	6	5
40	20	20	17	17	21	24	24	17	19	18	22	19	17	23	19
Capacity	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3

Table 35: Solution for AMS problem Example 3 from day 1 to 30.

Airplane\Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1																M1														
2																				M1										
3																														
4					M1																									
5														M1																
6																					M1									
7																			M1											
8						M1																								
9																														
10										M1																				
11														M1																
12																														
13																														
14																														
15																														
16																														
17																														
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31																														
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34																														
35																														
36																														
37																														
38																														
39																														
40																														

Table 36: Solution for AMS problem Example 3 from day 31 to 60.

Airplane\Day	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
1																														M2
2																														
3							M1																							
4																	M2	M2												
5																														
6																														
7																				M2										
8																						M2								
9														M1																
10																	M2													
11																												M2		
12																														
13							M1																							
14			M1																											
15																														
16						M1																								
17							M1	M1																						
18																														
19																			M1	M1										
20																														
21												M1																		
22												M1																		
23																														
24																														
25																	M2													
26																														
27																												M2		
28																										M2				
29												M1																		
30	M1																													
31																														
32		M1																												
33																														
34																						M2								
35																														
36	M1																													
37									M2																					
38																														
39																														
40			M1																											

Table 37: Solution for AMS problem Example 3 from day 61 to 90.

Airplane\Day	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
1																														
2				M2																										
3																M2														
4																													M3	
5	M2																													
6			M2																											
7																				M3										
8																														
9																														
10																							M3							
11																														
12										M2																				
13																M2														
14														M2																
15													M2	M2																
16																		M2												
17																M2														
18														M2																
19																														
20							M2																							
21																			M2											
22																		M2												
23				M2																										
24				M2	M2																									
25															M2															
26											M2																			
27																														
28																								M3						
29																														
30								M2																						
31							M2																							
32															M2															
33							M2																							
34																														
35											M2																			
36													M2																	
37										M2	M2																			
38					M2																									
39		M2																												
40										M2	M2																			

Table 38: Solution for AMS problem Example 3 from day 91 to 120.

Airplane\Day	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120
1													M3																	
2																	M3													
3																									M3					
4																														
5																			M3											
6															M3															
7																						M4								
8								M3																						
9	M2																													
10																														M4
11											M3																			
12																						M3								
13																									M3					
14																												M3		
15																												M3		
16																											M3			
17																								M3						
18																														M3
19	M3																													
20													M3																	
21																									M3					
22																								M3						
23															M3															
24																	M3													
25														M3	M3															
26																							M3							
27							M3																							
28																							M4							
29	M2																													M3
30																M3														
31																					M3									
32																							M3							
33																M3														
34					M3																									
35																													M3	
36																								M3						
37											M3																			
38																			M3											
39																										M3				
40																M3														

Table 39: Solution for AMS problem Example 3 from 121 to 150.

Airplane\Day	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150
1																										M4	M4			
2																														
3																														
4												M4																		
5																														
6																											M4			
7																														
8																								M4						
9																														
10																														
11																									M4					
12																														
13																														
14																														
15																														
16																														
17																														
18	M3																													
19																														
20																				M4	M4									
21																														
22																														
23																									M4					
24																												M4		
25																														
26																														
27																M4														
28																														
29																														
30																						M4								
31																														
32																														
33																									M4					
34																	M4													
35																														
36																														
37																														
38																														
39																														
40																								M4						

Example 4

Table 40: AMS Example 4 maintenance checks and maintenance interval data for airplanes 1 to 30.

Airplane	LT	UT	ST	M1	M2	M3	M4	M5
1	300	375	218	1	2	1	1	-
2	300	375	298	1	1	1	1	-
3	700	1000	530	1	1	1	1	3
4	150	275	127	1	1	1	1	-
5	400	600	87	1	1	1	-	-
6	600	750	409	2	1	1	1	-
7	400	600	400	1	1	1	1	1
8	400	600	509	1	1	1	1	-
9	150	275	144	1	1	1	-	-
10	600	750	178	1	1	1	1	-
11	300	375	306	1	1	1	1	-
12	300	375	191	1	1	1	2	-
13	700	1000	244	1	1	1	1	-
14	150	275	149	1	2	1	1	-
15	400	600	215	1	1	1	1	-
16	600	750	34	1	1	1	1	-
17	600	750	422	1	1	1	1	2
18	400	600	237	1	1	1	1	-
19	150	275	60	1	1	1	-	-
20	600	750	687	1	1	1	1	1
21	300	375	31	1	1	1	1	-
22	300	375	6	1	1	1	1	-
23	700	1000	490	1	2	1	1	-
24	150	275	210	1	1	1	1	-
25	300	375	174	1	1	1	1	1
26	600	750	315	1	1	1	1	-
27	600	750	125	1	1	1	1	-
28	300	375	250	1	1	3	1	1
29	150	275	256	1	1	1	1	-
30	600	750	188	1	1	1	1	-

Table 41: AMS Example 4 maintenance checks and maintenance interval data for airplanes 31 to 50.

Airplane	LT	UT	ST	M1	M2	M3	M4	M5
31	300	375	232	1	1	1	1	-
32	300	375	61	1	2	1	1	-
33	700	1000	406	1	1	1	1	-
34	150	275	197	1	1	1	1	-
35	400	600	35	1	1	1	-	-
36	600	750	72	1	1	2	1	-
37	400	600	61	1	1	1	1	1
38	400	600	301	1	1	1	1	-
39	150	275	93	1	1	1	-	-
40	600	750	404	1	1	1	1	1
41	300	375	253	1	1	1	1	-
42	300	375	197	1	1	1	1	-
43	700	1000	635	1	1	1	1	1
44	150	275	171	1	2	1	1	-
45	400	600	460	1	1	1	1	-
46	600	750	379	1	1	1	1	-
47	400	600	419	1	2	1	1	2
48	400	600	183	1	1	1	1	-
49	150	275	111	1	1	1	-	-
50	600	750	729	1	1	1	1	1

Table 42: Solution for AMS problem Example 4 from day 1 to 30.

Airplane\Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1																			M1											
2										M1																				
3																				M1										
4																							M1							
5																														
6																				M1	M1									
7											M1																			
8								M1																						
9																											M1			
10																														M1
11									M1																					
12																						M1								
13																														
14																			M1											
15																														
16																														
17																		M1												
18																												M1		
19																														
20				M1																										
21																														
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23																					M1									
24											M1																			
25																	M1													
26																									M1					
27																														
28										M1																				
29				M1																										
30																														M1
31																	M1													
32																														
33																								M1						
34													M1																	
35																														
36																														
37																														M1
38																							M1							
39																														
40																		M1												
41															M1															
42																					M1									
43															M1															
44																	M1													
45												M1																		
46																						M1								
47										M1																				
48																														
49																														
50		M1																												

Table 43: Solution for AMS problem Example 4 from day 31 to 60.

Airplane\Day	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
1																								M2						
2																														M2
3																														
4											M1																			
5																														
6												M2																		
7																								M2						
8																														
9																						M2								
10																														
11																														
12	M1																													
13																														
14		M1																												
15										M1																				
16																											M2			
17																														
18														M1																
19										M2																				
20							M1																							
21									M1																					
22																							M2							
23																														
24																M2														
25																														
26			M1																											
27									M2																					
28																														
29																														
30																														
31							M1																							
32																														
33																														
34																														
35									M1																					
36																														
37																														
38																														
39																														
40																														
41																														
42																														
43																														
44																														
45																														
46																														
47																														
48																														
49																														
50																														

Table 44: Solution for AMS problem Example 4 from day 61 to 90.

Airplane\Day	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
1		M2	M2																											
2																														
3																														
4				M2																										
5																								M2						
6			M2																											
7													M3																	
8																														
9																						M2								
10						M2																								
11																														
12						M2																								
13											M2																			
14	M2	M2																												
15																			M2											
16															M2															
17																														
18														M2																
19																														
20																M3														
21													M2																	
22															M2															
23	M2	M2																												
24																														
25																M3														
26								M2																						
27												M2																		
28								M3	M3	M3																				
29																														
30						M2																								
31	M2																													
32														M2	M2															
33				M2																										
34																														
35																								M2						
36																	M2													
37																														
38									M2																					
39																														
40																														
41																														
42					M2																									
43																														
44																														
45																														
46				M2																										
47												M3																		
48																	M2													
49																								M2						
50																M3														

Table 45: Solution for AMS problem Example 4 from day 91 to 120.

Airplane\Day	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120
1															M3															
2								M3																						
3										M3																				
4															M3															
5																											M3			
6																M3														
7														M4																
8									M3																					
9																														
10														M3																
11					M3																									
12													M3																	
13																					M3									
14												M3																		
15																										M3				
16																				M3										
17						M3																								
18																													M3	
19	M2																													M3
20																							M4							
21																			M3											
22																					M3									
23										M3																				
24					M3																									
25																M4														
26																				M3										
27																					M3									
28							M4																							
29																						M3								
30															M3															
31														M3																
32																			M3											
33													M3																	
34								M3																						
35																											M3			
36																						M3	M3							
37	M3																													
38																									M3					
39	M2																													
40			M3																											
41											M3																			
42																		M3												
43					M3																									
44											M3																			
45																	M3													
46																M3														
47													M4																	
48																											M3			
49																										M3				
50																							M4							

Table 46: Solution for AMS problem Example 4 from day 121 to 150.

Airplane\Day	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150
1																							M4							
2																						M4								
3																				M4										
4																											M4			
5																														
6																									M4					
7															M5															
8																							M4							
9	M3																													
10																						M4								
11																			M4											
12																			M4	M4										
13																														
14																					M4									
15																													M4	
16																									M4					
17														M4																
18																														M4
19																														
20																														M5
21																									M4					
22																										M4				
23																				M4										
24																		M4												
25														M5																
26																										M4				
27																													M4	
28					M5																									
29																														
30																								M4						
31																							M4							
32																								M4						
33																						M4								
34																			M4											
35																														
36																										M4				
37		M4																												
38																														M4
39	M3																													
40								M4																						
41																					M4									
42																								M4						
43															M4															
44																					M4									
45																												M4		
46																											M4			
47														M5	M5															
48																													M4	
49																														
50																														

Table 47: Solution for AMS problem Example 4 from day 151 to 180.

Airplane\Day	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180
1																														
2																														
3																												M5	M5	M5
4																														
5																														
6																														
7																														
8																														
9																														
10																														
11																														
12																														
13	M4																													
14																														
15																														
16																														
17																							M5	M5						
18																														
19																														
20																														
21																														
22																														
23																														
24																														
25																														
26																														
27																														
28																														
29	M4																													
30																														
31																														
32																														
33																														
34																														
35																														
36																														
37			M5																											
38																														
39																														
40															M5															
41																														
42																														
43																									M5					
44																														
45																														
46																														
47																														
48																														
49																														
50	M5																													

AMS with AMCA problem Example 2

Table 48: AMS with AMCA problem Example 2 flying hours and maintenance capacity slots from day 1 to 30.

Airplane\Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	8	12	10	12	11	11	8	9	12	9	11	9	7	10	10	9	11	10	10	10	12	9	11	12	9	12	10	12	12	12
2	9	8	7	8	9	9	9	7	7	7	9	9	7	8	9	9	9	9	8	8	9	7	8	8	7	9	7	9	9	9
3	25	20	22	23	20	26	24	22	23	23	25	22	26	25	23	22	22	21	24	22	26	25	23	21	24	23	22	25	25	24
4	8	7	6	8	8	6	7	6	8	8	8	7	6	7	8	6	8	6	8	8	7	7	8	8	6	8	7	7	6	8
5	9	11	11	12	9	11	12	13	11	13	10	9	12	11	12	10	13	10	11	10	10	10	11	13	12	10	13	13	10	9
6	18	17	18	17	18	17	18	16	17	19	19	16	16	17	18	19	17	19	16	17	17	17	16	17	19	17	16	16	18	16
7	18	20	22	22	21	18	20	18	19	19	22	21	19	18	20	20	21	19	22	19	22	20	19	19	18	21	20	20	19	20
8	13	10	10	11	10	11	12	14	13	10	13	12	12	11	12	14	13	12	13	12	13	13	10	10	14	14	12	14	12	10
9	6	4	7	7	5	6	5	6	4	6	6	7	5	5	4	6	6	5	4	7	7	6	4	5	6	7	5	6	4	4
10	17	22	17	20	18	23	17	19	17	23	16	18	19	16	22	23	22	24	24	23	21	16	19	24	17	22	16	18	17	22
11	8	7	5	6	10	8	5	10	6	8	5	8	6	7	6	8	7	8	5	8	10	10	5	5	7	5	10	8	5	8
12	7	7	6	8	6	8	10	5	7	5	9	10	5	8	9	6	9	5	7	6	5	10	5	8	6	5	9	7	8	10
13	7	8	10	5	5	10	7	5	8	9	10	10	8	7	6	8	7	10	5	5	9	5	7	6	6	5	6	9	6	5
14	11	11	7	13	13	10	8	12	11	8	10	13	13	10	12	10	9	13	12	11	11	9	9	9	12	9	8	7	12	10
15	11	10	9	11	11	10	12	9	10	8	12	7	11	8	11	10	8	12	7	13	8	11	9	12	12	9	12	12	12	10
16	9	10	12	11	13	7	8	13	9	8	11	10	10	13	13	12	10	11	12	13	13	11	13	11	11	9	10	12	9	11
17	11	7	10	9	13	7	10	7	11	7	11	7	10	13	8	12	8	9	10	12	7	7	10	11	8	9	10	10	9	9
18	9	7	8	9	13	12	11	13	7	7	8	13	7	13	12	12	11	10	11	11	9	12	13	10	10	10	7	12	10	12
19	13	8	12	10	10	10	12	10	12	9	12	12	11	10	13	13	11	13	11	7	8	12	9	8	9	10	10	13	12	9
20	11	13	8	11	12	9	8	10	12	10	12	12	10	9	13	13	11	13	13	10	8	7	11	9	13	10	11	10	11	11
Capacity	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2

Table 49: AMS with AMCA problem Example 2 flying hours and maintenance capacity slots from day 31 to 60.

Airplane\Day	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
1	12	10	10	9	11	10	12	11	8	12	12	8	12	10	8	9	9	9	8	10	8	8	11	9	10	8	11	10	8	10
2	7	7	9	9	8	9	8	7	9	8	7	9	7	7	7	8	8	9	8	7	8	7	8	8	8	8	9	7	7	7
3	24	20	23	20	20	24	23	26	25	23	25	21	21	21	21	20	21	23	21	24	26	20	26	21	24	24	24	22	24	21
4	8	8	6	6	6	6	8	8	8	6	6	8	7	8	7	7	7	8	6	7	7	6	6	8	8	8	7	6	6	8
5	13	11	13	13	11	10	9	10	11	13	13	11	10	10	11	9	10	9	12	12	11	13	11	12	9	11	11	12	11	10
6	18	18	18	19	16	19	17	18	16	17	18	16	19	17	17	17	19	19	18	16	18	19	16	16	19	19	17	18	19	19
7	19	22	18	18	19	22	22	20	22	20	19	18	21	22	21	22	19	19	19	21	21	19	19	21	22	18	20	18	21	18
8	12	14	12	14	11	13	11	10	11	14	13	14	11	11	10	13	12	12	11	10	12	10	12	14	10	14	11	11	12	11
9	7	7	5	7	6	6	4	6	5	4	6	7	6	7	4	6	7	6	4	6	5	5	5	7	4	5	6	7	4	6
10	24	22	22	23	17	18	19	23	17	23	23	18	22	23	19	19	22	22	24	20	21	23	21	21	16	18	19	21	16	16
11	6	9	5	10	8	7	9	8	10	5	5	5	6	6	8	8	9	9	6	8	7	6	6	8	8	10	10	5	7	6
12	10	6	9	7	10	6	10	6	6	7	9	7	7	8	5	9	8	10	5	8	9	5	9	6	10	6	10	7	8	9
13	5	8	10	9	5	10	5	5	9	6	9	6	5	10	5	7	5	8	5	7	7	5	8	6	7	6	7	8	10	7
14	12	12	8	7	7	13	8	7	8	8	9	11	9	10	9	12	10	7	11	8	11	10	7	12	8	13	8	10	11	8
15	13	12	7	10	10	7	8	12	8	10	13	13	11	8	8	13	11	12	13	7	9	7	7	10	8	11	12	12	10	8
16	11	9	11	10	12	11	11	13	8	11	11	9	12	8	12	10	9	8	9	8	7	13	9	13	11	9	7	10	9	12
17	8	11	9	8	9	13	13	13	12	12	9	12	12	11	11	9	8	11	9	9	8	10	9	12	9	13	9	12	9	12
18	12	12	7	13	11	13	13	11	13	7	12	7	12	7	9	13	10	12	8	10	10	9	13	8	9	9	7	8	10	9
19	10	8	7	10	11	12	10	11	7	11	9	11	10	7	8	10	12	13	7	9	8	7	9	10	10	11	11	7	9	10
20	8	10	12	8	11	9	7	9	7	11	10	9	13	13	8	8	8	11	7	10	9	13	8	13	12	11	7	7	7	8
Capacity	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2

Table 50: AMS with AMCA problem Example 2 flying hours and maintenance capacity slots from day 61 to 90.

Airplane\Day	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
1	11	9	9	10	9	10	9	12	9	8	10	12	10	12	12	9	12	12	8	8	8	10	8	9	10	12	10	8	9	10
2	9	7	9	7	8	7	7	8	9	7	7	9	8	7	8	7	9	7	7	8	9	9	8	9	9	7	7	7	8	8
3	25	21	20	20	20	20	24	21	26	21	23	25	22	21	24	22	26	20	22	22	20	25	25	23	25	20	22	26	24	26
4	8	6	7	6	8	8	7	8	6	8	7	6	6	7	6	8	7	6	6	8	8	6	8	6	7	7	6	6	8	7
5	11	12	9	9	13	11	10	11	9	10	10	10	12	13	9	9	11	10	12	9	11	13	13	9	13	11	12	13	12	9
6	17	18	17	17	19	17	16	18	16	19	16	19	19	18	17	16	17	16	17	19	19	19	18	19	16	19	18	19	18	19
7	22	20	20	19	22	20	19	19	18	19	20	20	20	19	18	22	21	20	22	21	18	19	22	20	19	21	19	21	19	20
8	13	11	11	11	10	12	10	14	11	13	11	11	10	10	14	10	14	12	11	11	10	11	13	11	10	13	11	14	13	10
9	6	7	7	5	7	4	7	4	6	6	5	7	7	5	4	4	4	7	7	6	7	7	5	5	5	5	6	7	4	7
10	24	16	21	18	17	18	24	22	19	24	17	21	21	21	22	22	16	21	18	21	17	24	19	20	20	17	19	20	20	22
11	10	8	8	6	10	5	10	10	10	10	7	9	5	5	8	8	5	9	8	8	7	9	6	10	8	7	10	10	9	8
12	5	9	8	8	6	9	10	10	7	10	9	6	8	7	10	6	6	5	9	5	9	6	6	10	8	8	10	8	6	5
13	9	9	8	9	5	6	10	6	10	9	10	10	6	7	7	9	5	8	7	6	8	7	6	9	6	5	5	5	7	10
14	12	9	12	13	10	7	11	7	12	7	13	12	9	8	8	10	10	12	10	13	10	12	11	8	8	8	11	8	12	7
15	11	11	11	9	10	10	8	11	10	9	8	10	11	8	11	7	7	13	12	8	9	12	8	7	9	8	11	7	13	13
16	10	13	11	8	13	11	8	8	7	8	8	8	11	10	8	9	9	12	10	10	7	8	13	8	8	7	10	12	11	13
17	9	9	7	10	9	12	7	13	11	12	9	12	10	9	13	8	9	13	11	8	10	7	12	10	9	9	9	7	7	11
18	12	10	13	13	10	8	10	12	9	9	8	9	11	10	13	9	12	13	11	11	12	11	11	11	13	7	7	9	13	11
19	10	10	8	9	13	12	10	7	13	7	8	10	12	11	7	10	13	11	7	10	7	7	8	9	9	13	10	12	13	7
20	11	7	8	12	10	13	10	13	8	8	8	7	13	7	9	10	8	8	12	7	11	13	7	10	12	10	9	11	10	11
Capacity	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2

Table 51: AMS with AMCA problem Example 2 maintenance interval data.

Airplane	LT	UT	ST
1	100	275	251
2	150	275	134
3	600	800	223
4	100	275	251
5	300	375	264
6	500	600	352
7	500	600	225
8	300	375	120
9	100	275	85
10	500	600	66
11	150	275	152
12	100	275	74
13	150	275	23
14	100	275	16
15	100	275	199
16	100	275	31
17	150	275	45
18	150	275	109
19	150	275	237
20	100	275	204

Table 52: AMS with AMCA problem Example 2 man-day required to complete maintenance checks for the airplanes 1 to 10.

Airplane-Check	Ground time cost SR/HR	Avionics	Power Plant	Airframe	Cabin
1-M1	9007	38	27	11	19
1-M2	7689	21	20	16	18
1-M3	8244	23	26	21	19
2-M1	11961	17	33	17	26
2-M2	8481	41	25	14	24
2-M3	11589	15	24	14	26
3-M1	6095	37	24	50	24
3-M2	7128	26	25	12	23
4-M1	11823	36	34	27	17
4-M2	6320	31	29	20	30
4-M3	11512	41	11	21	26
5-M1	5629	15	21	27	25
5-M2	9918	55	23	40	37
5-M3	8222	17	14	14	16
6-M1	8562	34	11	35	22
6-M2	11466	29	40	43	27
6-M3	7498	32	25	16	33
7-M1	5490	16	25	20	18
7-M2	9053	38	35	34	36
7-M3	7944	22	22	24	28
8-M1	8254	39	21	23	34
8-M2	10013	17	11	18	25
8-M3	6975	21	11	33	18
9-M1	6739	35	23	14	30
9-M2	10708	16	22	25	34
10-M1	6323	23	31	24	31
10-M2	8943	41	43	39	46
10-M3	9795	16	27	26	34

Table 53: AMS with AMCA problem Example 2 man-day required to complete maintenance checks for the airplanes 11 to 20.

Airplane-Check	Ground time cost SR/HR	Avionics	Power Plant	Airframe	Cabin
11-M1	11173	15	10	31	27
11-M2	10339	19	21	27	21
11-M3	7103	40	30	29	36
12-M1	5239	37	16	29	24
12-M2	6332	21	11	10	20
13-M1	9276	16	22	29	37
13-M2	10424	32	21	33	35
14-M1	7539	18	14	15	26
14-M2	7003	18	26	27	40
14-M3	8936	32	24	35	37
15-M1	11877	16	13	33	24
15-M2	9302	30	11	32	24
15-M3	8082	27	21	32	33
16-M1	6786	34	19	16	31
16-M2	10344	22	33	10	16
16-M3	11189	33	27	15	38
17-M1	6843	48	30	35	25
17-M2	6660	36	17	28	24
17-M3	10215	28	12	16	35
18-M1	11621	18	25	32	27
18-M2	9897	31	12	21	34
18-M3	10217	20	33	26	15
19-M1	10270	26	15	15	30
19-M2	11076	16	25	30	31
19-M3	6331	33	33	33	51
20-M1	11495	49	47	50	36
20-M2	7259	30	28	24	36
20-M3	10757	24	28	35	34
Number of workers availble		45	35	35	40

After step 1 is performed we get the data in table 54.

Table 54: AMS with AMCA problem Example 2 maintenance checks data*.

Airplane	M1	M2	M3
1	1	1	1
2	1	1	1
3	2	1	-
4	1	1	1
5	1	2	1
6	1	2	1
7	1	1	1
8	1	1	1
9	1	1	-
10	1	2	1
11	1	1	1
12	1	1	-
13	1	1	-
14	1	1	1
15	1	1	1
16	1	1	1
17	2	1	1
18	1	1	1
19	1	1	2
20	2	1	1

*M1, M2 and M3 are the maintenance need to be performed in sequence.

Solution for Example 2

Table 55: Solution for Example 2 AMS from day 1 to 30.

Airplane\Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	M1																											M2		
2																		M1												
3																									M1	M1				
4			M1																											
5										M1																				
6															M1															
7																		M1												
8																						M1								
9																														
10																										M1				
11																M1														
12																													M1	
13																														
14																							M1							
15								M1																						
16																							M1							
17																					M1	M1								
18																	M1													
19			M1																											M2
20						M1	M1																							

Table 56: Solution for Example 2 AMCA schedule from day 1 to 30.

	Aircrafts\Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	Avionics		38																										21		
	Power Plant		27																										20		
	Airframe		11																										16		
	Cabin		19																										18		
2	Avionics																		17												
	Power Plant																		33												
	Airframe																		17												
	Cabin																		26												
3	Avionics																										37				
	Power Plant																										24				
	Airframe																									15	35				
	Cabin																										24				
4	Avionics			36																											
	Power Plant			34																											
	Airframe			27																											
	Cabin			17																											
5	Avionics										15																				
	Power Plant										21																				
	Airframe										27																				
	Cabin										25																				
6	Avionics															34															
	Power Plant															11															
	Airframe															35															
	Cabin															22															
7	Avionics																			16											
	Power Plant																			25											
	Airframe																			20											
	Cabin																			18											
8	Avionics																						39								
	Power Plant																						21								
	Airframe																						23								
	Cabin																						34								
9	Avionics																														
	Power Plant																														
	Airframe																														
	Cabin																														
10	Avionics																											23			
	Power Plant																											31			
	Airframe																											24			
	Cabin																											31			
11	Avionics																15														
	Power Plant																10														
	Airframe																31														
	Cabin																27														
12	Avionics																												37		
	Power Plant																												16		
	Airframe																												29		
	Cabin																												24		
13	Avionics																														
	Power Plant																														
	Airframe																														
	Cabin																														
14	Avionics																								18						
	Power Plant																								14						
	Airframe																								15						
	Cabin																								26						
15	Avionics								16																						
	Power Plant								13																						
	Airframe								33																						
	Cabin								24																						
16	Avionics																							34							
	Power Plant																							19							
	Airframe																							16							
	Cabin																							31							
17	Avionics																				45	3									
	Power Plant																					30									
	Airframe																					35									
	Cabin																					25									
18	Avionics																	18													
	Power Plant																	25													
	Airframe																	32													
	Cabin																	27													
19	Avionics			26																											16
	Power Plant			15																											25
	Airframe			15																											30
	Cabin			30																											31
20	Avionics						45	4																							
	Power Plant						35	12																							
	Airframe						35	15																							
	Cabin							36																							

Table 57: Solution for Example 2 AMS from day 31 to 60.

Airplane\Day	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
1																									M3					
2																					M2									
3																														M2
4											M2																			
5													M2	M2																
6																			M2	M2										
7																		M2												
8																						M2								
9				M1																										
10																										M2	M2			
11																								M2						
12																														
13						M1																								
14																							M2							
15					M2																									
16																M2														
17															M2															
18												M2																		
19																												M3	M3	
20			M2																											

Table 58: Solution for Example 2 AMCA schedule from day 31 to 60.

	Aircrafts\Day	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
1	Avionics																									23					
	Power Plant																									26					
	Airframe																									21					
	Cabin																									19					
2	Avionics																					41									
	Power Plant																					25									
	Airframe																					14									
	Cabin																					24									
3	Avionics																														26
	Power Plant																														25
	Airframe																														12
	Cabin																														23
4	Avionics											31																			
	Power Plant											29																			
	Airframe											20																			
	Cabin											30																			
5	Avionics													45	10																
	Power Plant														23																
	Airframe													35	5																
	Cabin														37																
6	Avionics																				29										
	Power Plant																			35	5										
	Airframe																			8	35										
	Cabin																				27										
7	Avionics																		38												
	Power Plant																		35												
	Airframe																		34												
	Cabin																		36												
8	Avionics																						17								
	Power Plant																						11								
	Airframe																						18								
	Cabin																						25								
9	Avionics				35																										
	Power Plant				23																										
	Airframe				14																										
	Cabin				30																										
10	Avionics																											41			
	Power Plant																										35	8			
	Airframe																										35	4			
	Cabin																										6	40			
11	Avionics																							19							
	Power Plant																							21							
	Airframe																							27							
	Cabin																							21							
12	Avionics																														
	Power Plant																														
	Airframe																														
	Cabin																														
13	Avionics						16																								
	Power Plant						22																								
	Airframe						29																								
	Cabin						37																								
14	Avionics																							18							
	Power Plant																							26							
	Airframe																							27							
	Cabin																							40							
15	Avionics					30																									
	Power Plant					11																									
	Airframe					32																									
	Cabin					24																									
16	Avionics																	22													
	Power Plant																	33													
	Airframe																	10													
	Cabin																	16													
17	Avionics																36														
	Power Plant																17														
	Airframe																28														
	Cabin																24														
18	Avionics												31																		
	Power Plant												12																		
	Airframe												21																		
	Cabin												34																		
19	Avionics																												33		
	Power Plant																												33		
	Airframe																												33		
	Cabin																												40	11	
20	Avionics			30																											
	Power Plant			28																											
	Airframe			24																											
	Cabin			36																											

Table 59: Solution for Example 2 AMS from day 61 to 90.

Airplane\Day	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
1																														
2																									M3					
3																														
4																			M3											
5																	M3													
6																							M3							
7																		M3												
8																								M3						
9												M2																		
10																										M3				
11																														M3
12				M2																										
13										M2																				
14																				M3										
15		M3																												
16															M3															
17													M3																	
18									M3																					
19																														
20	M3																													

Table 60: Solution for Example 2 AMCA schedule from day 61 to 90.

	Aircrafts\Day	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
1	Avionics																														
	Power Plant																														
	Airframe																														
	Cabin																														
2	Avionics																									15					
	Power Plant																									24					
	Airframe																									14					
	Cabin																									26					
3	Avionics																														
	Power Plant																														
	Airframe																														
	Cabin																														
4	Avionics																			41											
	Power Plant																			11											
	Airframe																			21											
	Cabin																			26											
5	Avionics																	17													
	Power Plant																	14													
	Airframe																	14													
	Cabin																	16													
6	Avionics																							32							
	Power Plant																							25							
	Airframe																							16							
	Cabin																							33							
7	Avionics																		22												
	Power Plant																		22												
	Airframe																		24												
	Cabin																		28												
8	Avionics																								21						
	Power Plant																								11						
	Airframe																								33						
	Cabin																								18						
9	Avionics												16																		
	Power Plant												22																		
	Airframe												25																		
	Cabin												34																		
10	Avionics																										16				
	Power Plant																										27				
	Airframe																										26				
	Cabin																										34				
11	Avionics																												40		
	Power Plant																												30		
	Airframe																												29		
	Cabin																												36		
12	Avionics				21																										
	Power Plant				11																										
	Airframe				10																										
	Cabin				20																										
13	Avionics										32																				
	Power Plant										21																				
	Airframe										33																				
	Cabin										35																				
14	Avionics																				32										
	Power Plant																				24										
	Airframe																				35										
	Cabin																				37										
15	Avionics		27																												
	Power Plant		21																												
	Airframe		32																												
	Cabin		33																												
16	Avionics															33															
	Power Plant															27															
	Airframe															15															
	Cabin															38															
17	Avionics													28																	
	Power Plant													12																	
	Airframe													16																	
	Cabin													35																	
18	Avionics									20																					
	Power Plant									33																					
	Airframe									26																					
	Cabin									15																					
19	Avionics																														
	Power Plant																														
	Airframe																														
	Cabin																														
20	Avionics	24																													
	Power Plant	28																													
	Airframe	35																													
	Cabin	34																													

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